# Transient puzzles

Chryssa Kouveliotou
NASA's MSFC

# AUTHORS

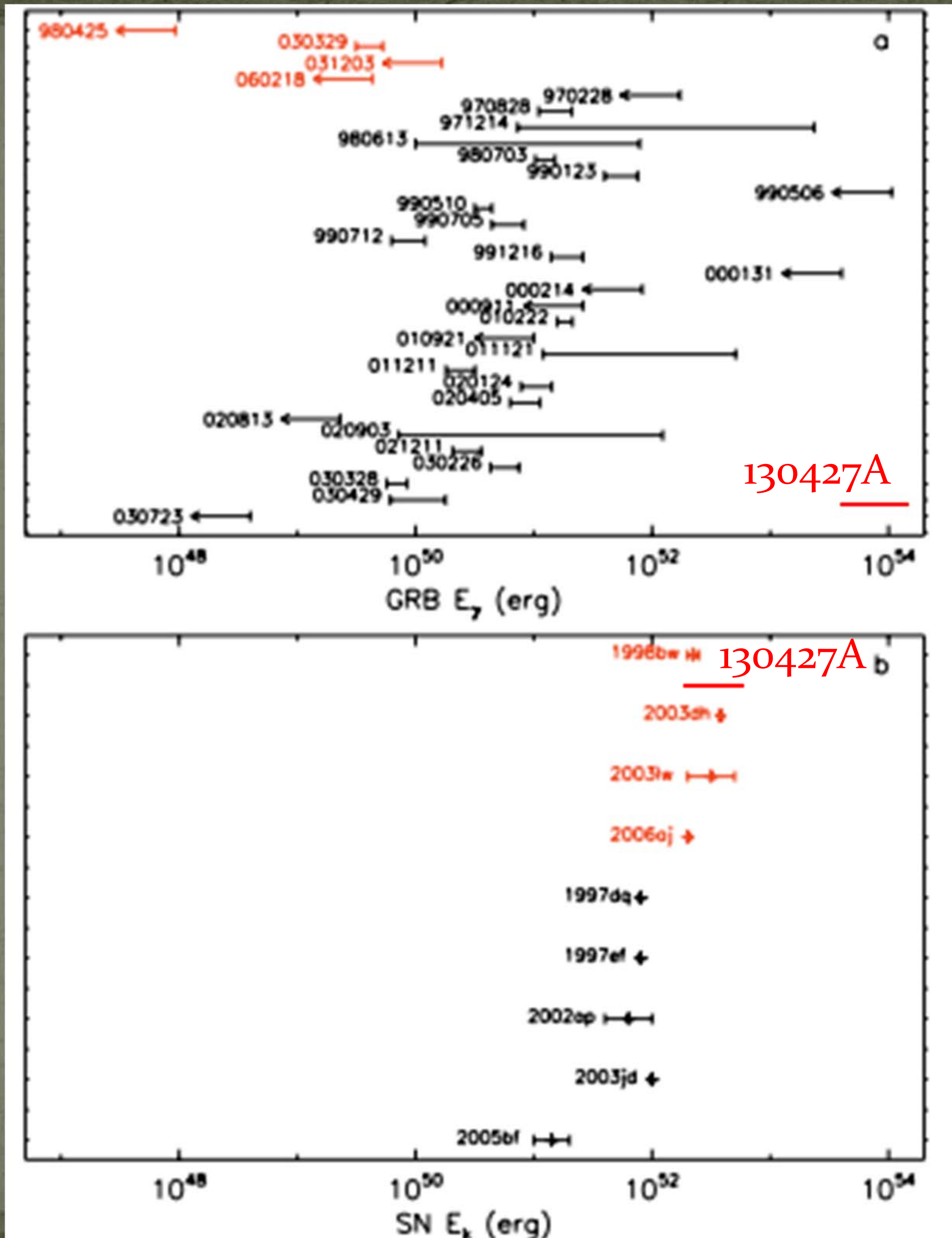
**GRB 130427A**

C. Kouveliotou, J. Granot, J. L. Racusin, E. Bellm, G. Vianello, S. Oates, C. L. Fryer, S. E. Boggs, F. E. Christensen, W. W. Craig, C. D. Dermer, N. Gehrels, C. J. Hailey, F. A. Harrison, A. Melandri, J. E. McEnery, C. G. Mundell, D. K. Stern[1], G. Tagliaferri, and W. W. Zhang

# GRB 130427A / SN 2013cq

**An exceptional event**

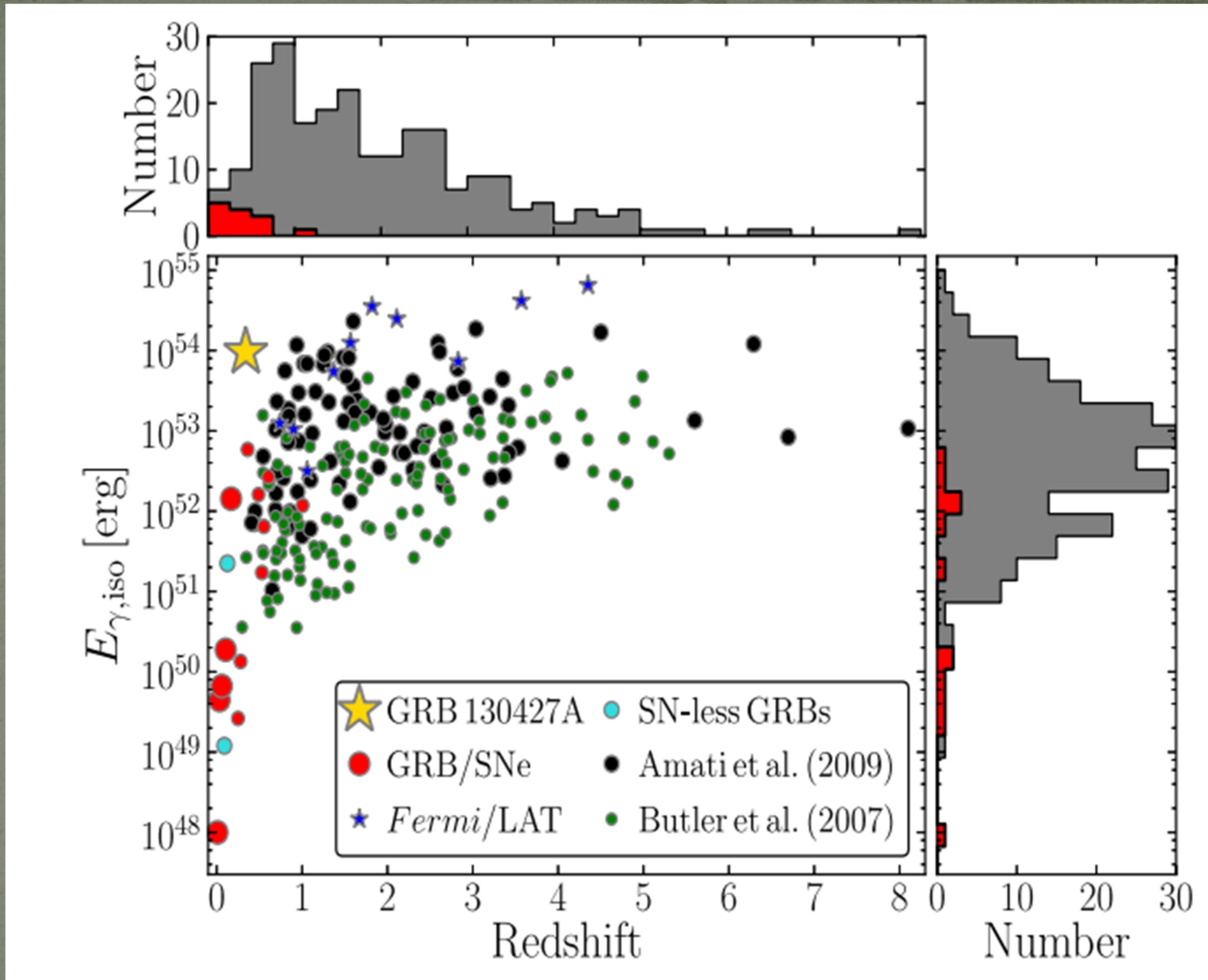
- Energetics: $E_{iso} = 1.4 \times 10^{54}$ erg – highest of all GRB-SNe associated events
- Highest Fluence = $4.9 \times 10^{-3}$ ergs cm$^{-2}$ (10 keV – 100 GeV)
- First X-ray afterglow emission detection above 10 keV
- First bright GRB with an SN at low z (0.33399±0.0002)
- One of the brightest GRBs
  - Saturated Fermi/GBM
  - Brightest burst ever detected with Fermi/LAT
- The highest energy photon from a GRB: 95 GeV
- The longest-lasting GeV emission ~ 20 hrs




GRB 130427A is similar to the most luminous, high-redshift GRBs common GRB central engine across z and isotropic energies

Bright GRBs are also associated with SNe

**Kaneko et al. 2007**


Number
30
20
10
0
$10^{55}$
$10^{54}$
$10^{53}$
$10^{52}$
$10^{51}$
$10^{50}$
$10^{49}$
$10^{48}$
$E_{\gamma,\mathrm{iso}}$ [erg]
GRB 130427A
GRB/SNe
*Fermi*/LAT
SN-less GRBs
Amati et al. (2009)
Butler et al. (2007)
0 1 2 3 4 5 6 7 8
Redshift
0 10 20 30
Number

Xu etal. 2013

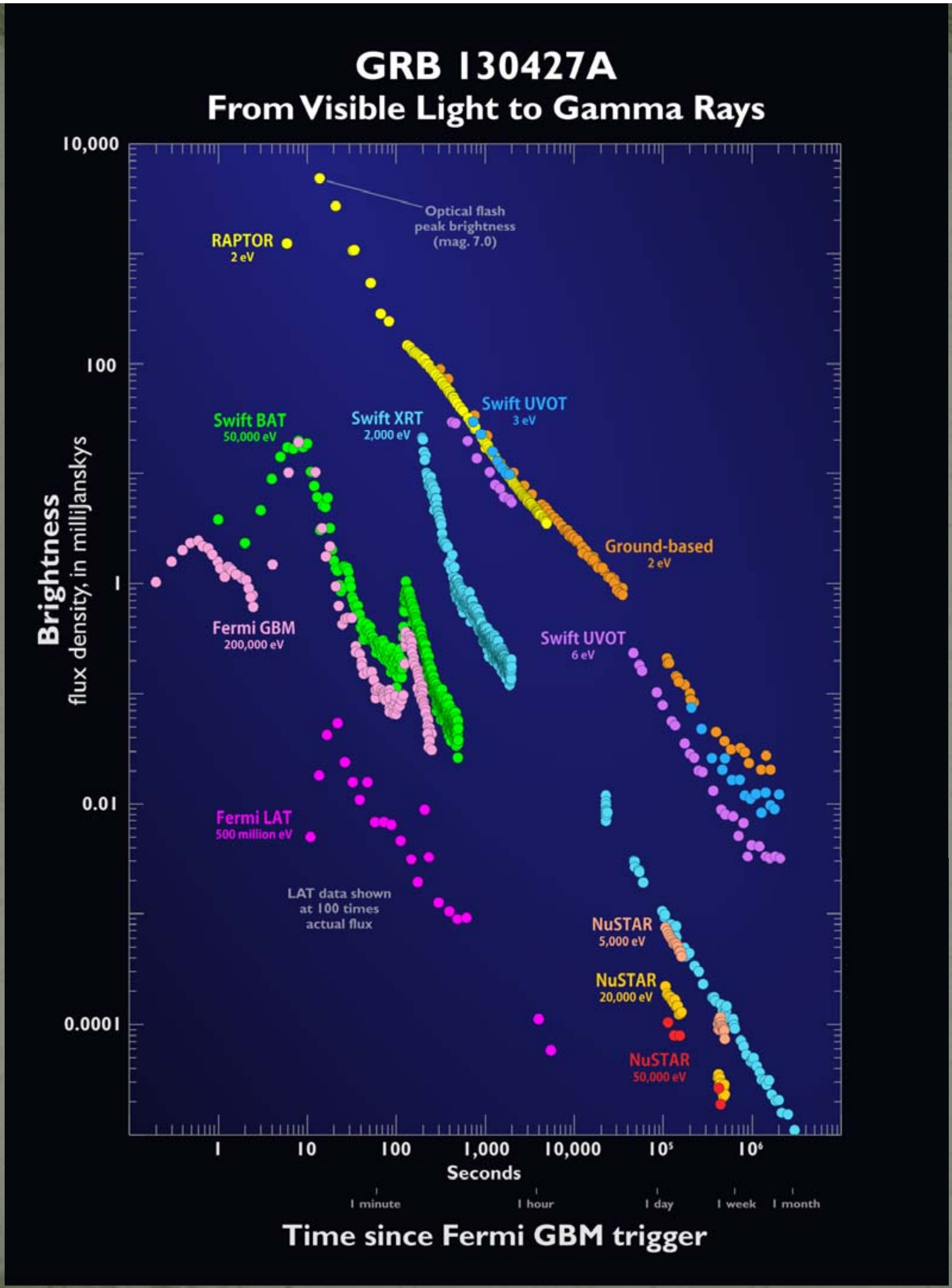
# Multi-wavelength Observations

PROMPT EMISSION

- Swift/BAT: 50– 150 keV
- Fermi/GBM: 10 – 40000 keV
- Raptor: 6580 Å (Sloan r band)

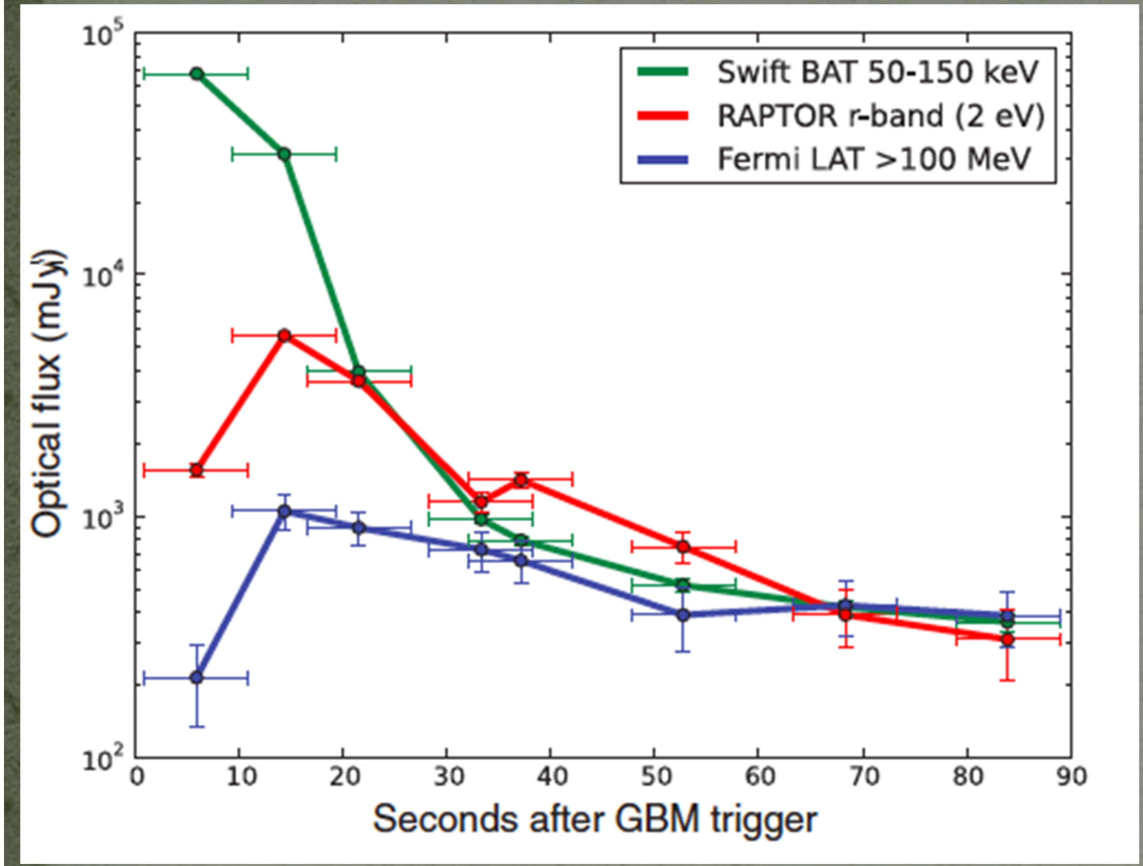
AFTERGLOW EMISSION

- Fermi/LAT: >10 MeV – 100 GeV
- NuSTAR: 3-79 keV
- Swift/XRT: 2-10 keV


GRB 130427A
From Visible Light to Gamma Rays
Optical flash peak brightness (mag. 7.0)
RAPTOR 2 eV
Swift BAT 50,000 eV
Swift XRT 2,000 eV
Swift UVOT 3 eV
Ground-based 2 eV
Fermi GBM 200,000 eV
Swift UVOT 6 eV
Fermi LAT 500 million eV
LAT data shown at 100 times actual flux
NuSTAR 5,000 eV
NuSTAR 20,000 eV
NuSTAR 50,000 eV
Brightness
flux density, in millijanskys
10,000
100
1
0.01
0.0001
1
10
100
1,000
10,000
$10^5$
$10^6$
Seconds
1 minute
1 hour
1 day
1 week
1 month
Time since Fermi GBM trigger

NASA's GSFC

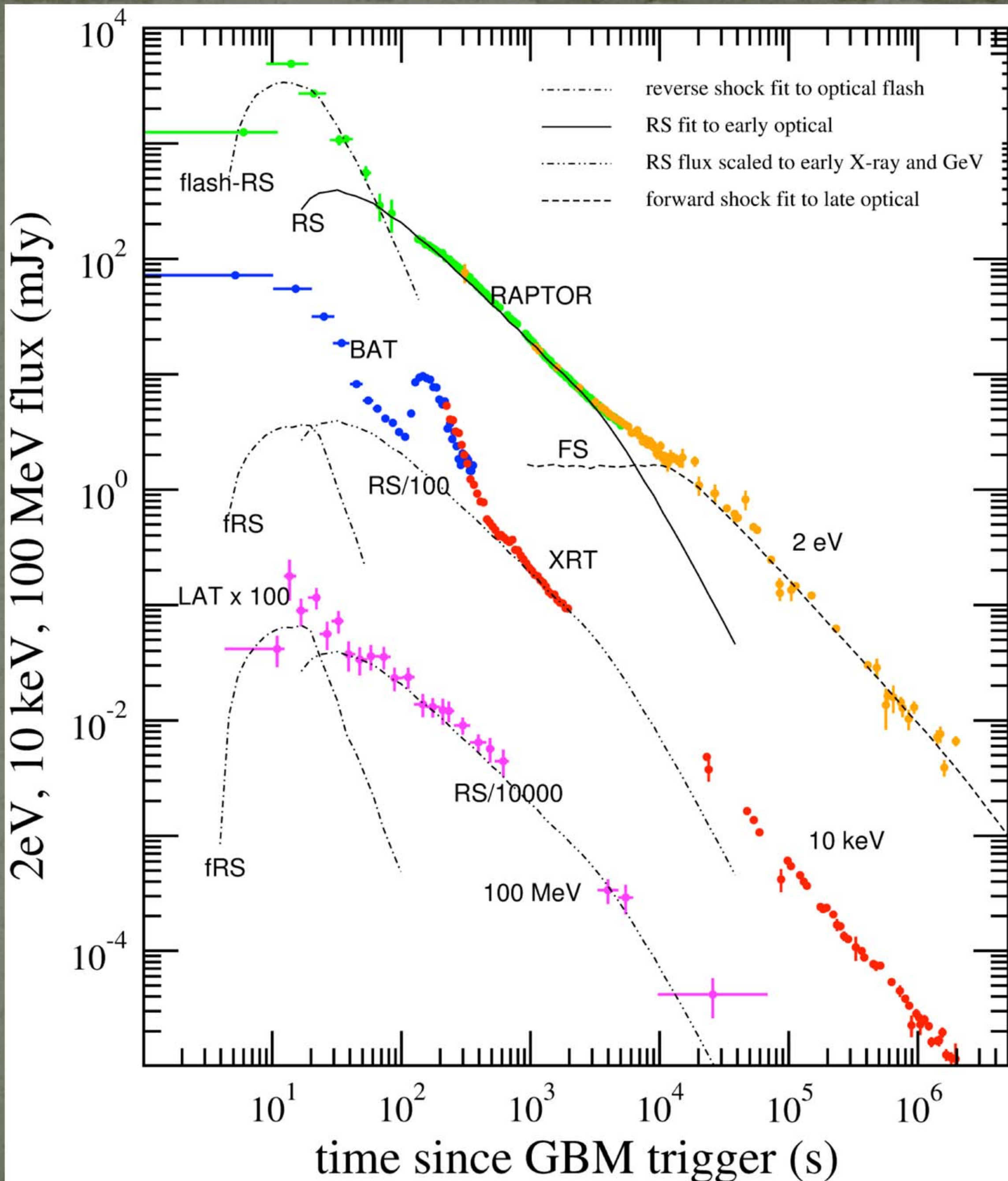
# Prompt Optical Flash




- $7^{th}$ mag peak in r band
- Peak correlated with >100 MeV
- Peak delayed wrt prompt keV emission
- Optical emission decayed steeply

**Vestrand et al. 2013**

**Optical peak is due to reverse shock emission**

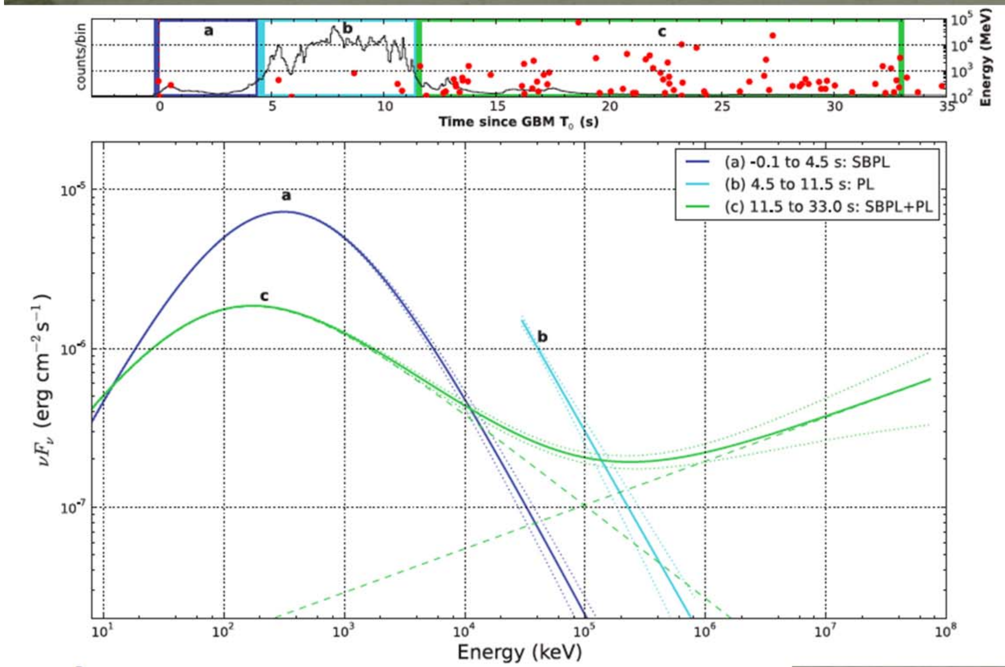


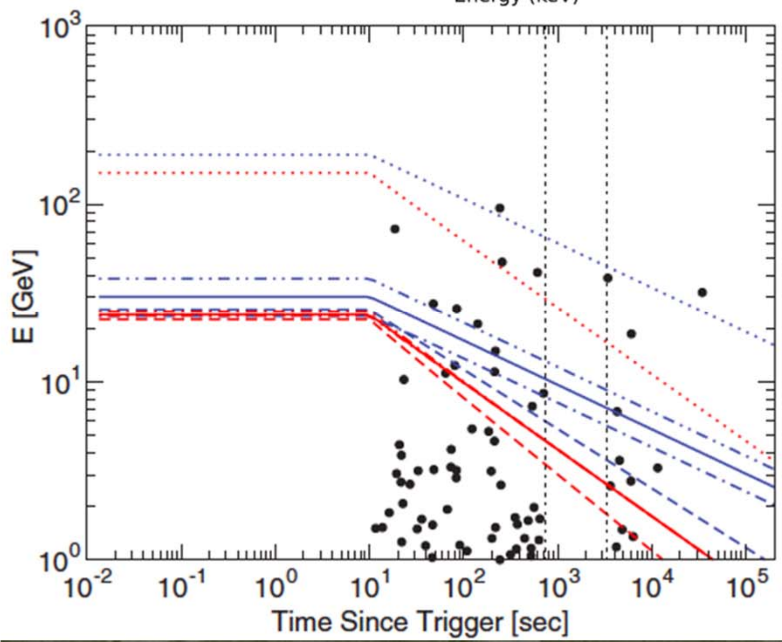

Three episodes of emission (windlike ambient medium density $n \sim r^{-2}$):

- Flash-RS
- RS
- Forward shock

**Vestrand et al. 2013**

# Fermi/LAT observations




What is the nature of the late >
>10 GeV photons ?

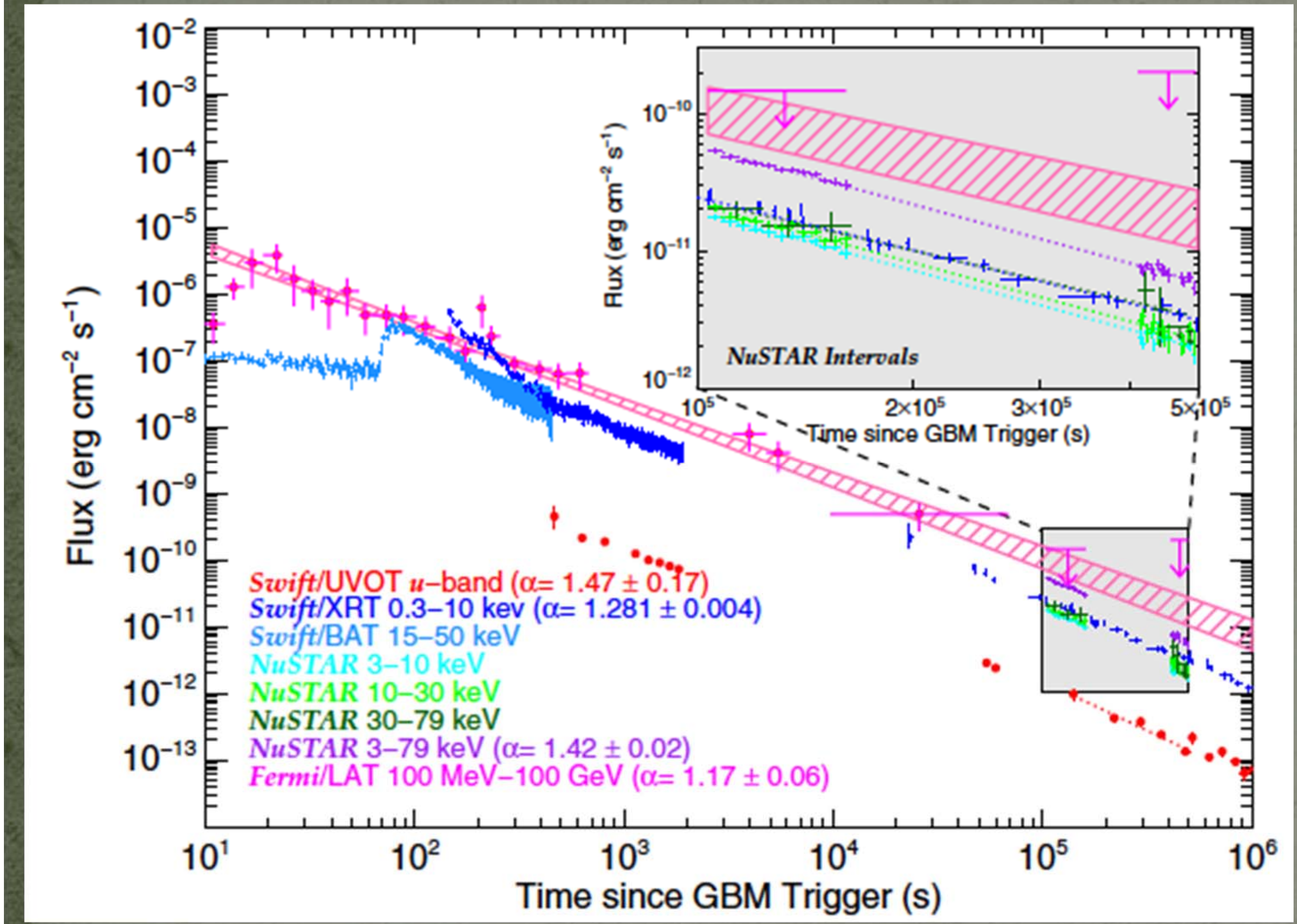
Non-thermal synchrotron radiation emitted by electrons accelerated by shock

Fermi acceleration is not supported by the limits on the maximum synchrotron photon energy.

Is there another component in the spectra that could resolve the nature of the emission?

**Ackermann et al. 2013**

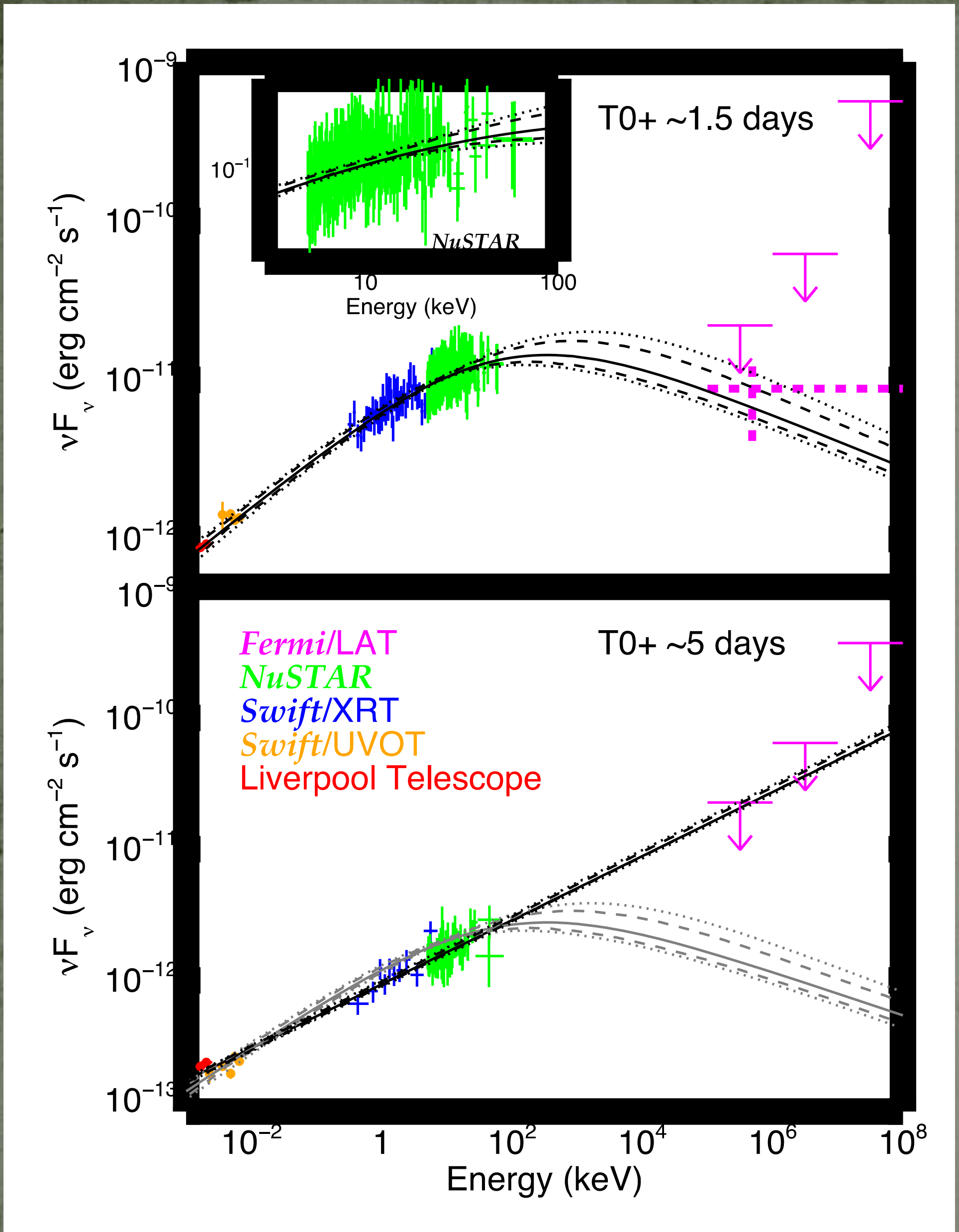
# NuSTAR observations




No evidence of extra component in the NuSTAR **lightcurve** 1 and 5 days after trigger:

**decay trend consistent with earlier data from Fermi and Swift**

**Kouveliotou et al. 2013**




No evidence of extra component in the NuSTAR **spectra** 1 and 5 days after trigger:

**Single component consistent with extrapolation of data from LAT at one day after trigger**

**The NuSTAR data are essential in constraining the shape of the broadband spectra**

**Kouveliotou et al. 2013**

# Conclusions

- The combined optical, XRT, NuSTAR , and Fermi/LAT UL SED at ~ 1.5 days is perfectly consistent with the theoretically expected SBPL spectral shape from optical to GeV energies, without any unaccounted for flux, and the flux at all these energies decays at a similar rate.
- The NuSTAR results provide the strongest direct observational support to date for an afterglow synchrotron origin of late-time >10 GeV Fermi/LAT photons. Such an origin challenges particle acceleration models in afterglow shocks.
- The NuSTAR results provide an important challenge for our understanding of particle acceleration and magnetic field amplification in relativistic shocks.

# Magnetar States

- Quiescent
- Active
  - Several 100s of bursts (storms) – 4 sources
  - Giant Flares (3 sources one each)
  - Few 10s of bursts (3 sources)
  - <10 bursts (10 sources)
  - No bursts (4 sources)

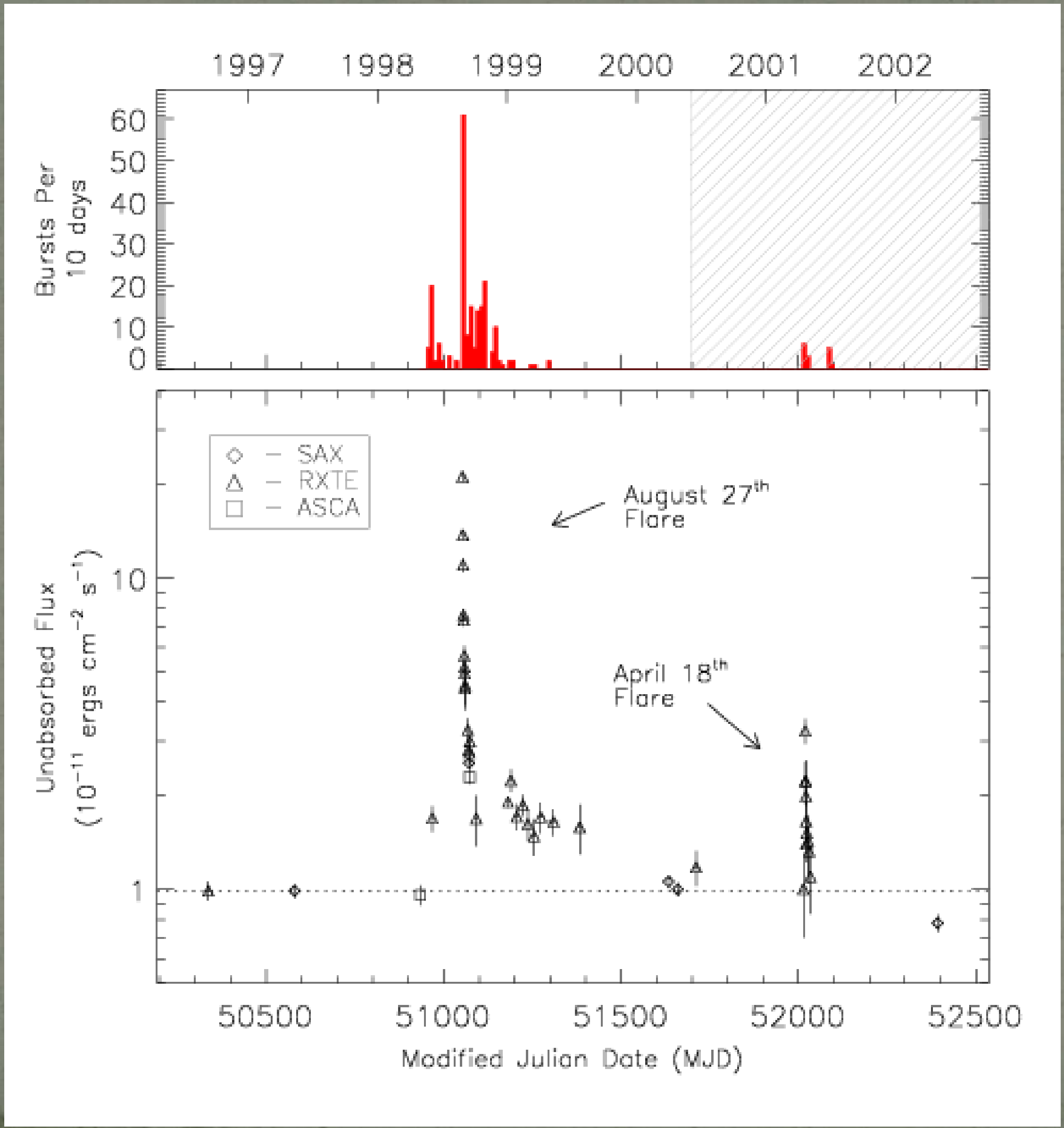
# 1. Burst effects in:

- Persistent X-ray Flux
- Pdot trend
- Pulse profile
- Source environment

# 2. GBM burst catalog 2008-14

# 3. Time resolved spectroscopy of bright GBM bursts

# Persistent flux

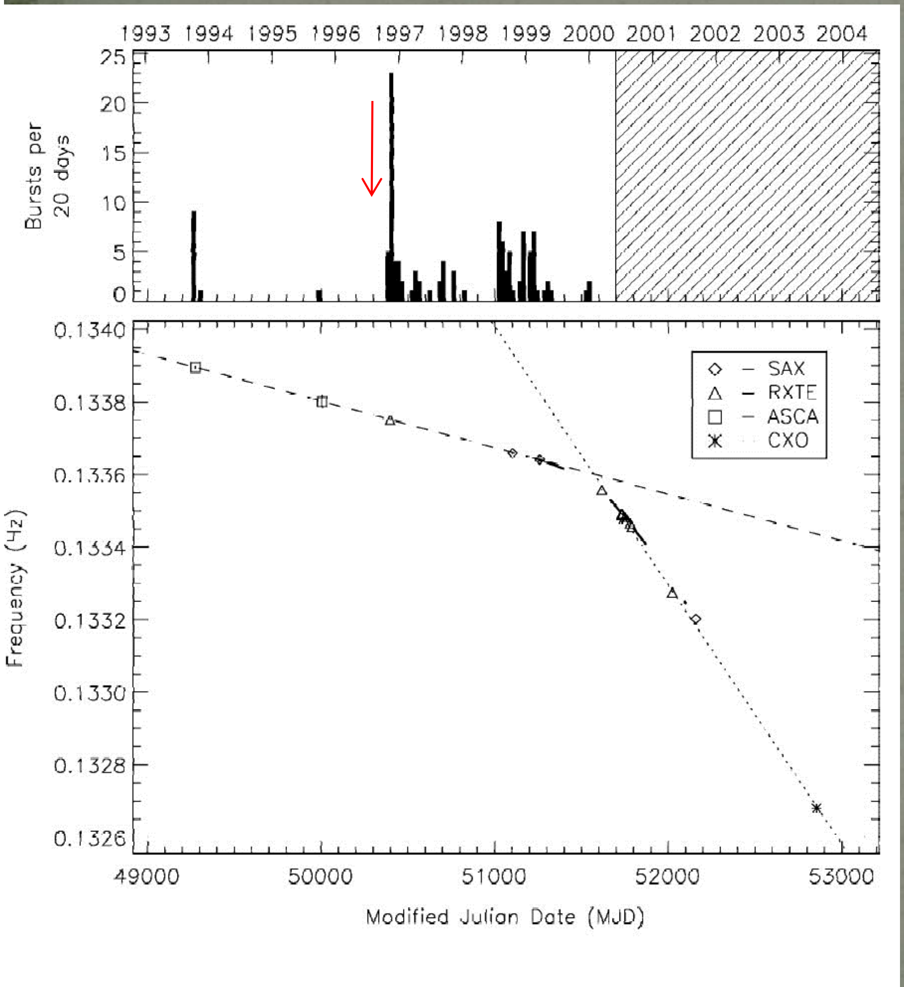



SGR 1900+14

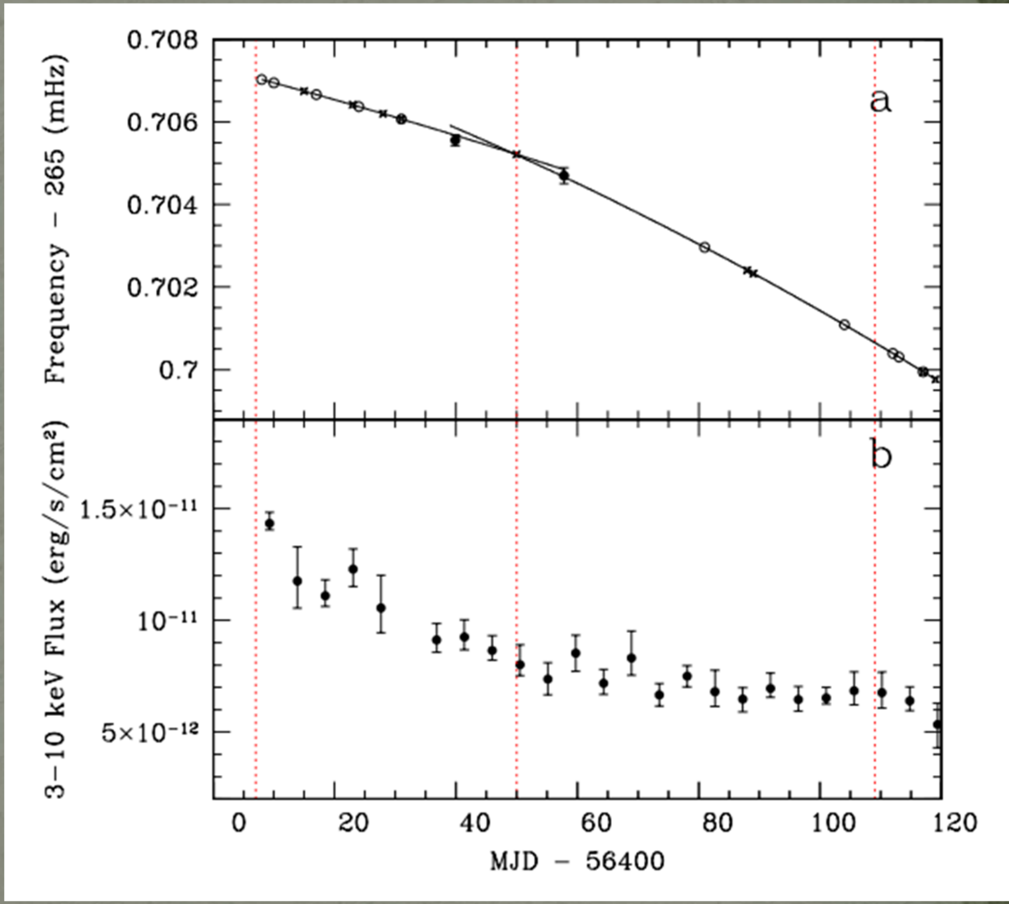
Woods et al. 2002

# Pdot

SGR 1806-20



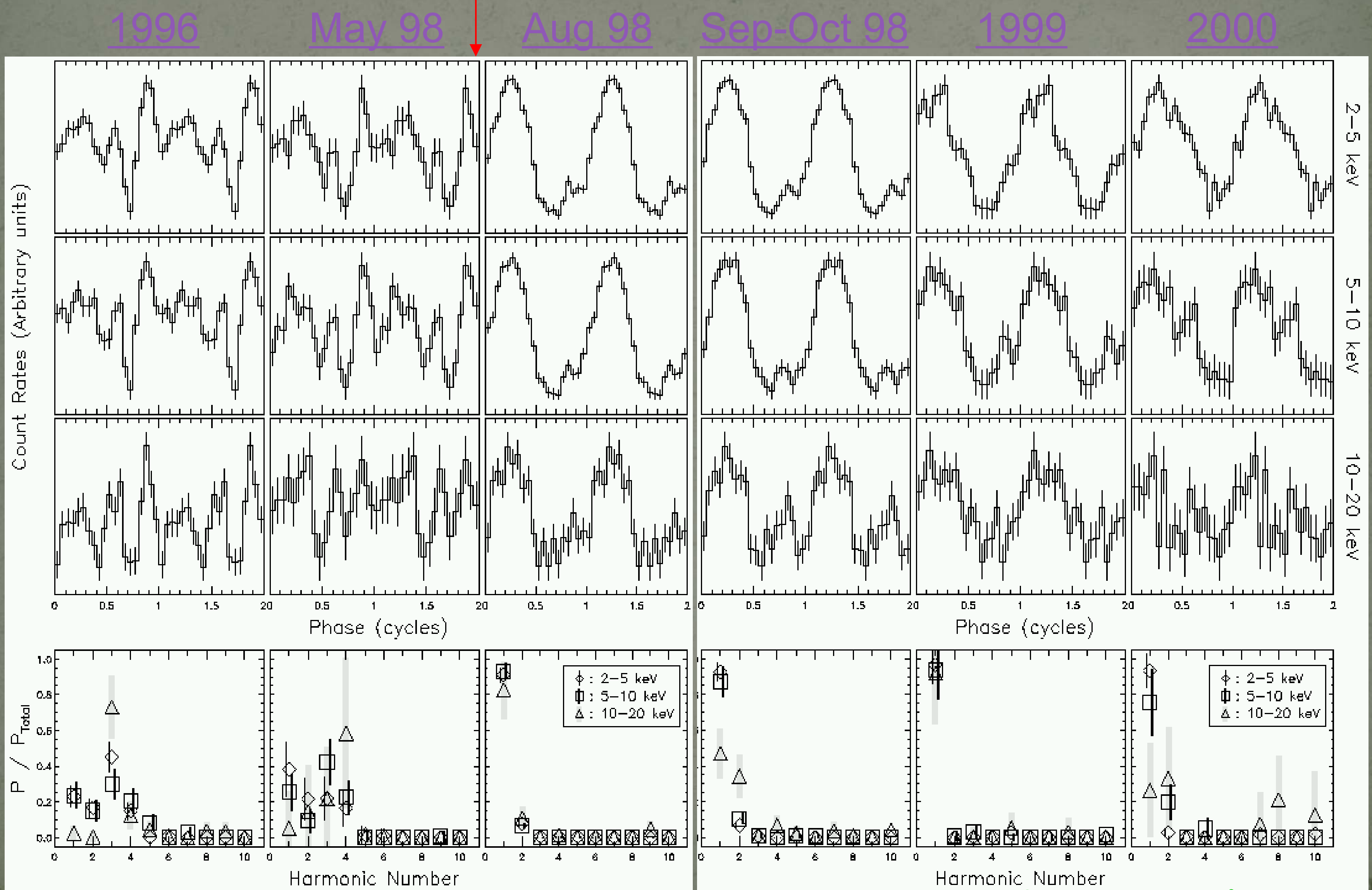

SGR J1745-2900




Woods et al 2002

Kaspi et al. 2014

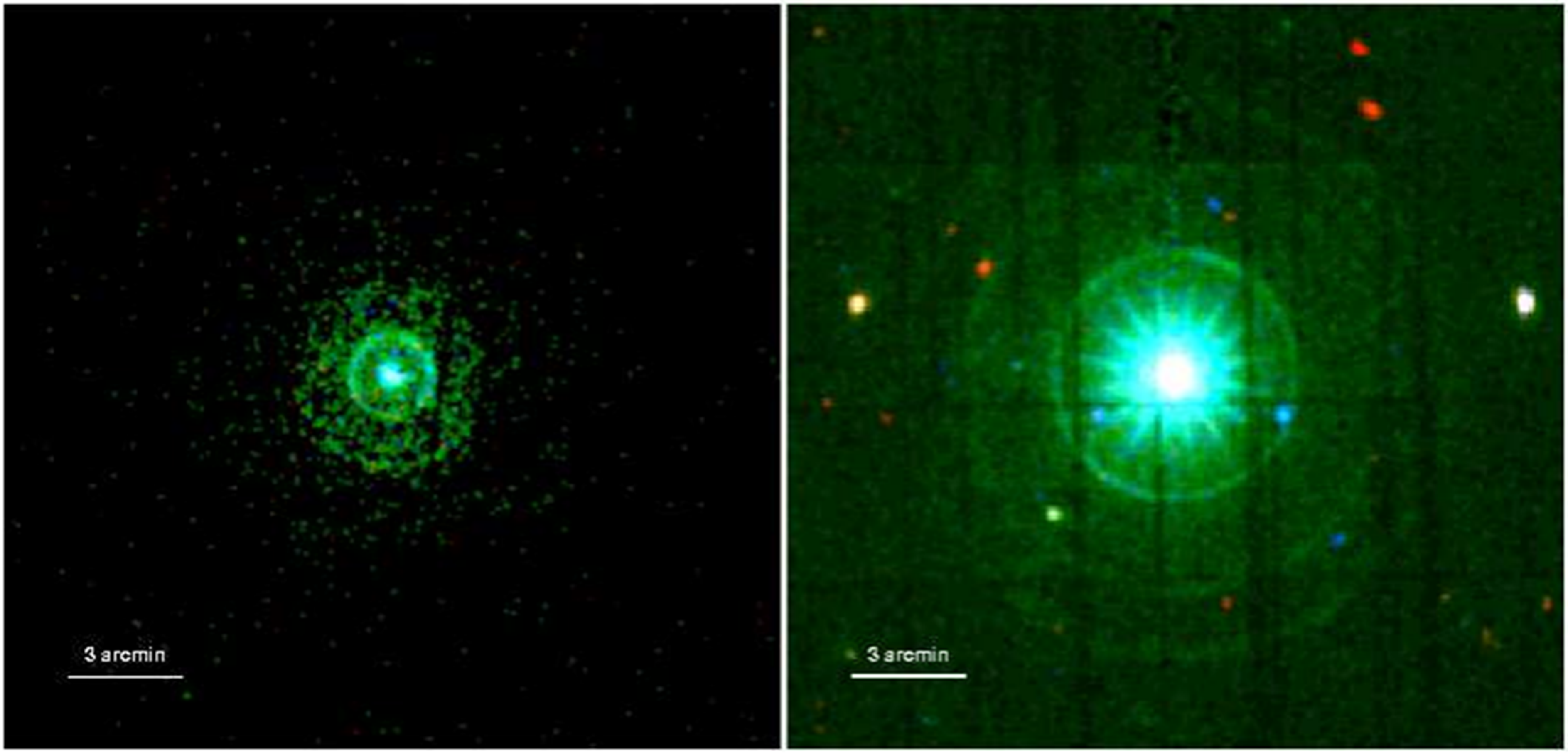
# Pulse profile




Gogus et al. 2002

# Environment

## Rings around SGR J1550-5418




Tiengo et al, 2010

# Environmen
## SGR J1834.9 - 0846

- **Discovery**: *Swift* triggered on 2011 August 7. Fermi/GBM triggered 3.3 hours later on a second burst. *Swift* triggered one more time on 2011 August 30. Total of 3 bursts.

- **Counterparts:** No optical or IR counterpart detection

- **Location:** *Chandra* ToO 11/08/22, CXOU J183452.1-084556

  R.A. = $18^h\ 34^m\ 52^s.118$, dec = $-08^\circ\ 45'\ 56''.02$

- **Timing:** *RXTE/PCA* ToO 11/08/9-10 reveals coherent pulsations at

  $\nu = 0.402853(2)$ Hz -> P = 2.4823018(1) s

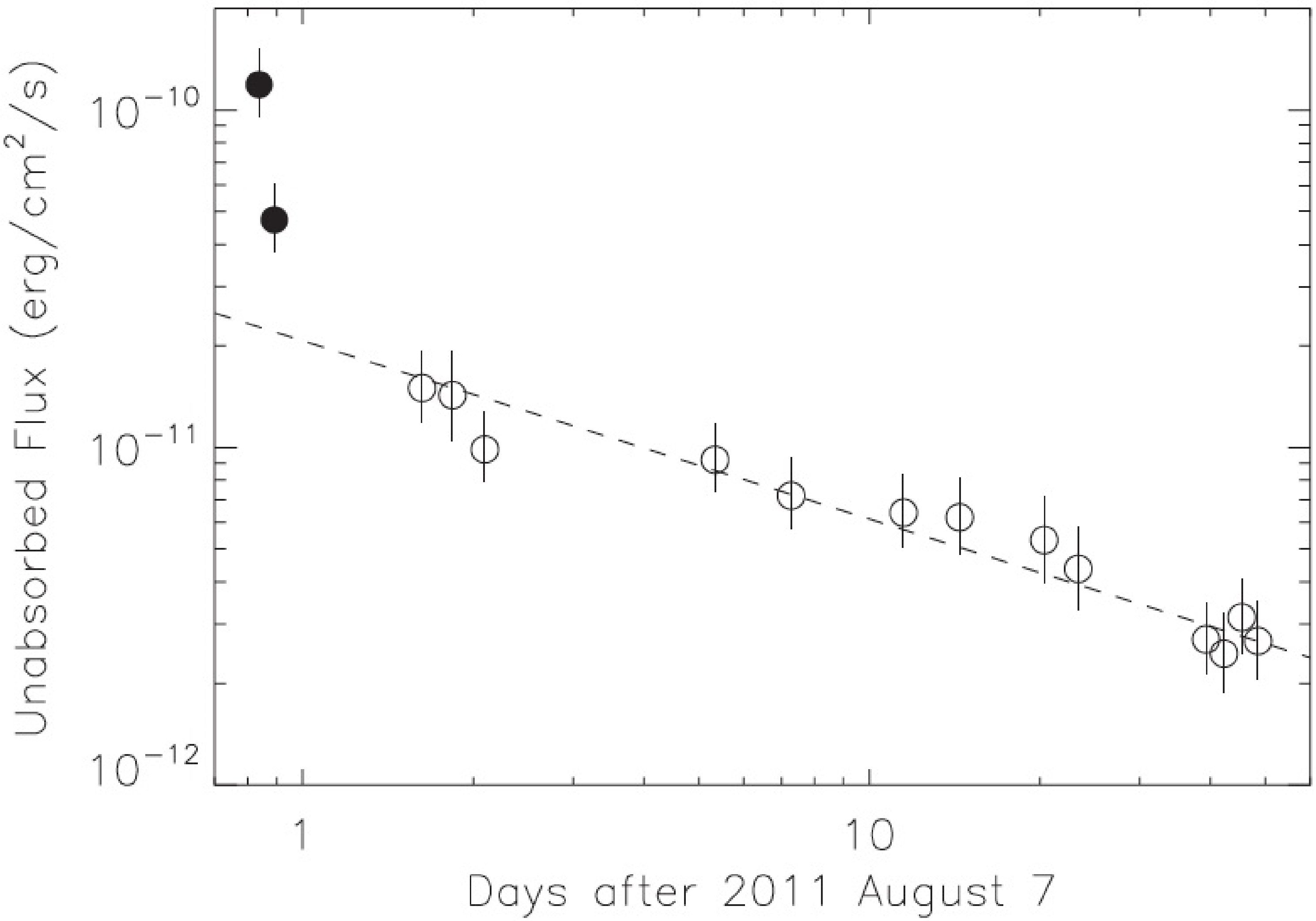
  Continuous *RXTE/PCA* monitoring over 2 weeks revealed

  $\nu = -1.3(2) \times 10^{-12}$ Hz/s => B = $1.4 \times 10^{14}$ G

- **Source field:** Very rich with high-energy sources:

  SNR W41, HESS J1834-087, 2FGL J1834.3-0848, PSR/PWN XMMU J183435.3-84443/CXOU J183434.9-084443

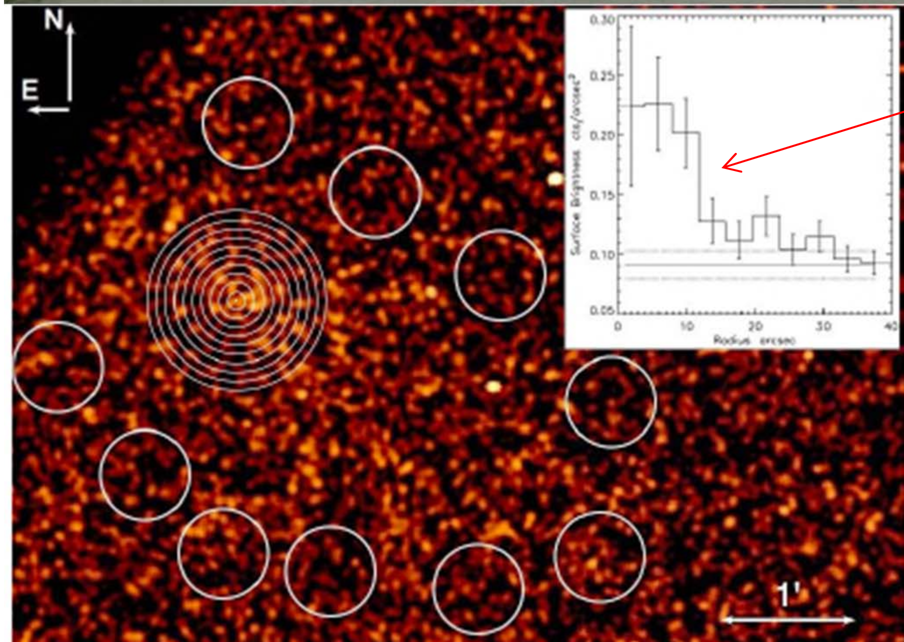
# Persistent emission X-ray light curve

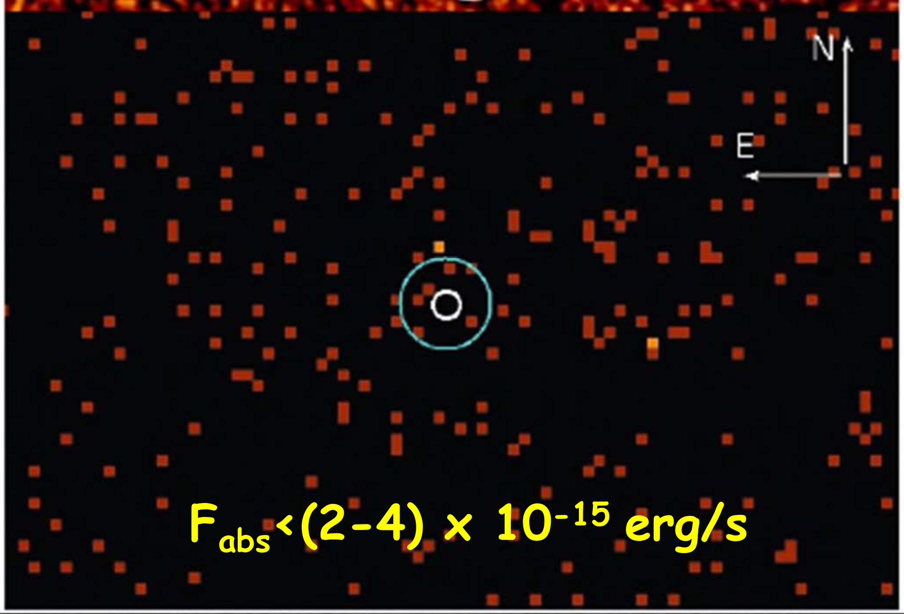



Kargaltsev et al. 2012

# The extended emission

CXO - 2005

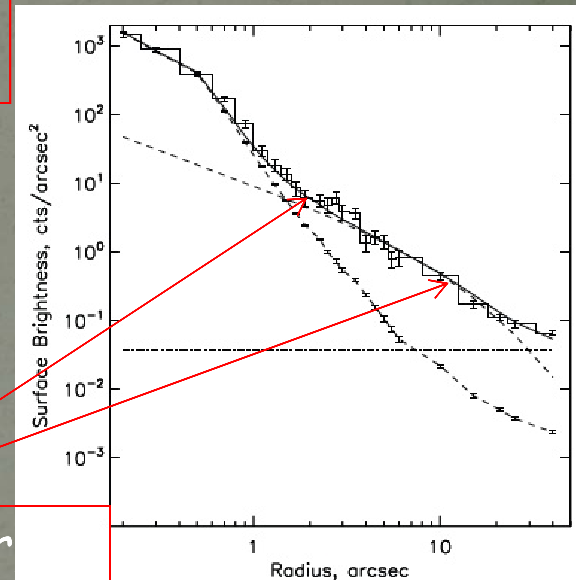


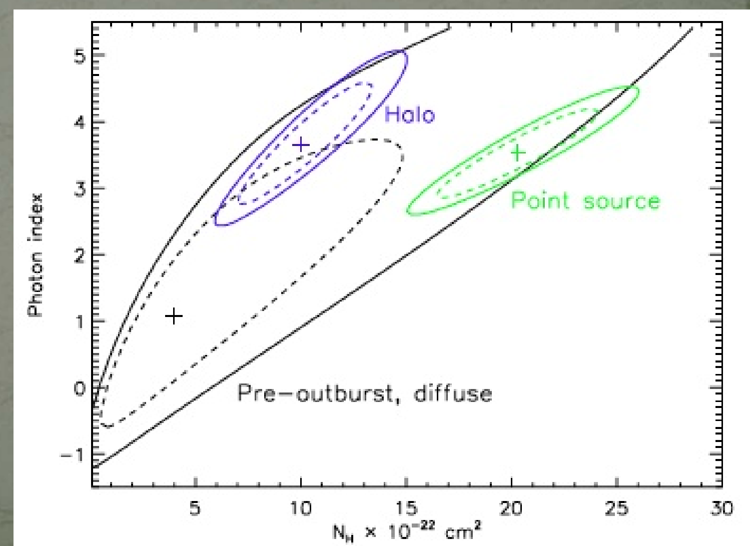

$F_{abs}$<(2-4) x $10^{-15}$ erg/s

<$12''$ @5.1σ
$12''$<r<$30''$ @3σ

CXO - 2011

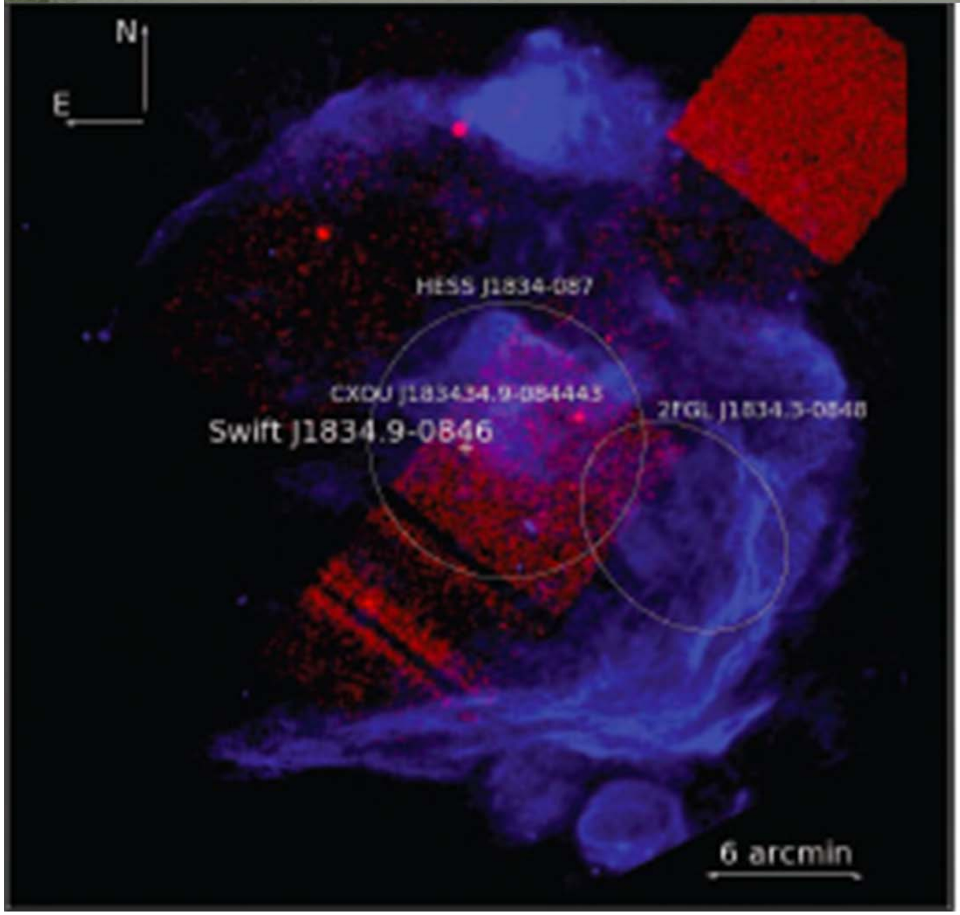


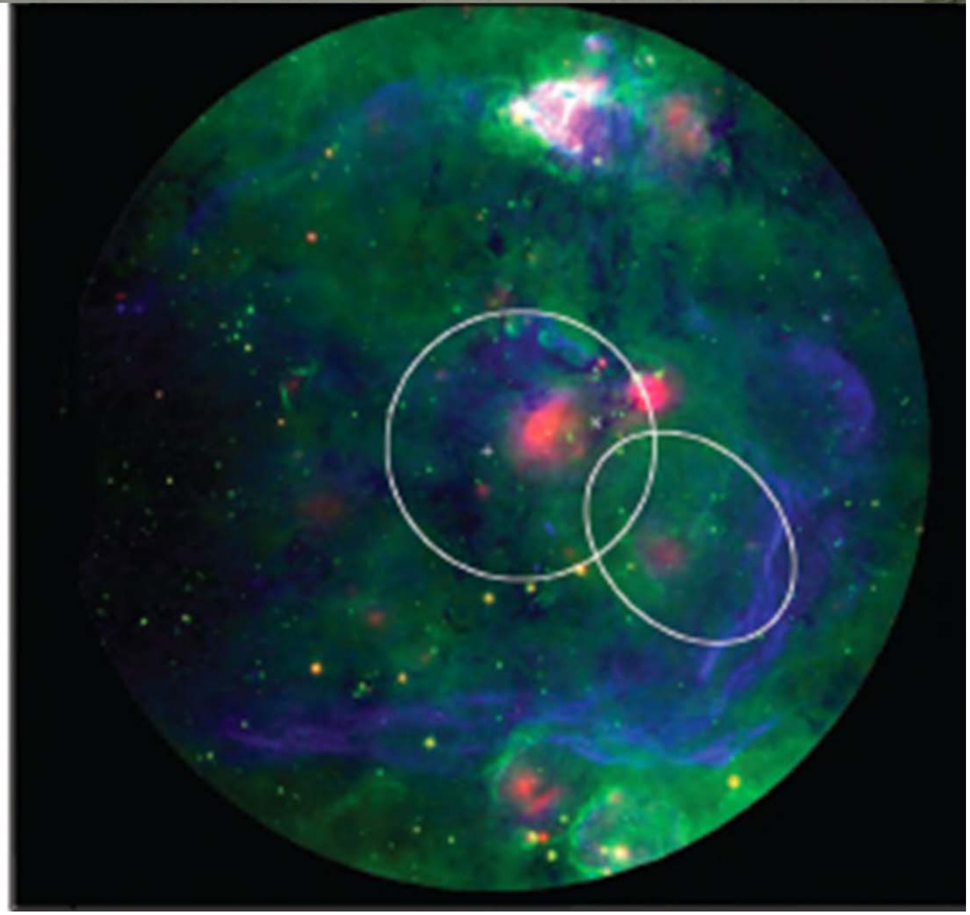

$F_{un}$ = 1.6x$10^{-12}$ er



# The source environment

- Close to the center of SNR W41
- Close to the center of the error box of HESS J1834-087 (circle)
- Near the GeV source 2FGL J1834.3-0848 (ellipse)
- PWN XMMU J183435.3-84443/CXOU J183434.9-084443 (similar $N_H$~$3x10^{23}$ $cm^{-2}$)

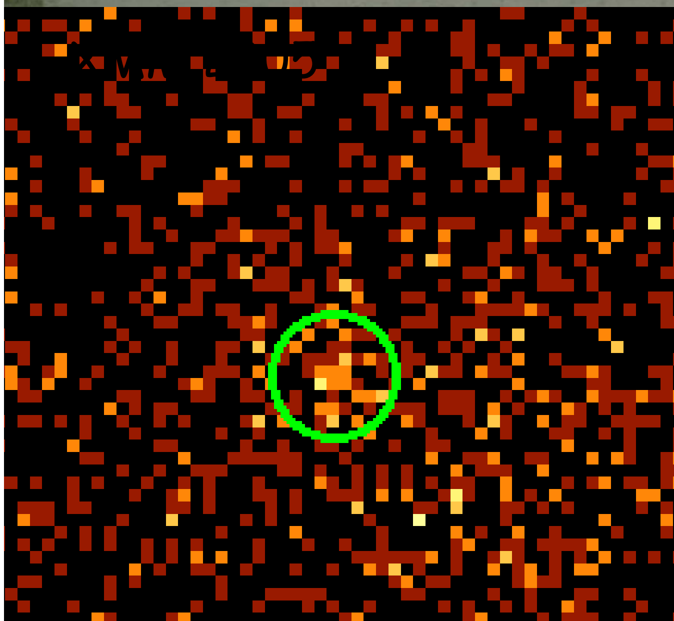


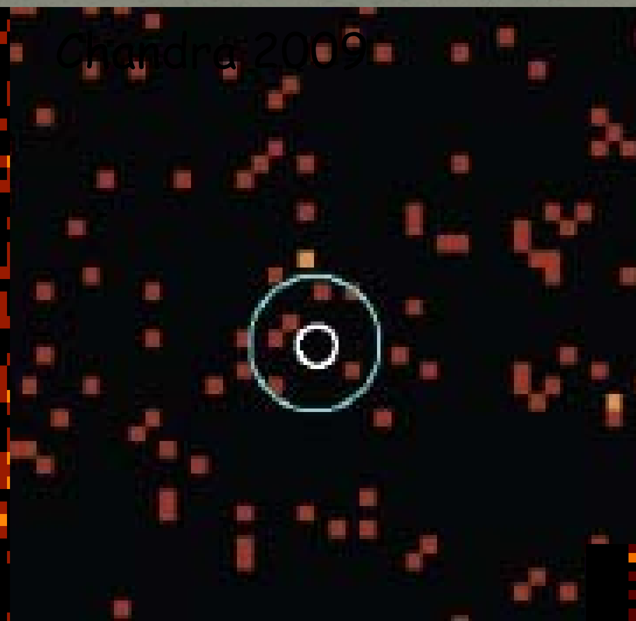



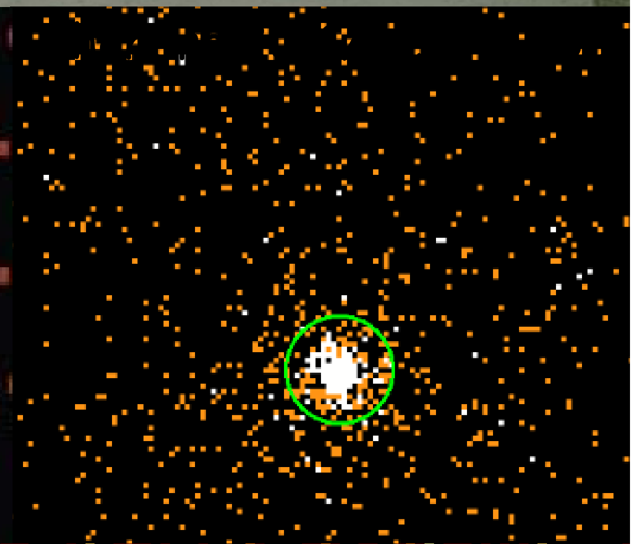
The environment of the source is very rich in HE sources – is there a connection between 1834 and the HESS/FGL sources?

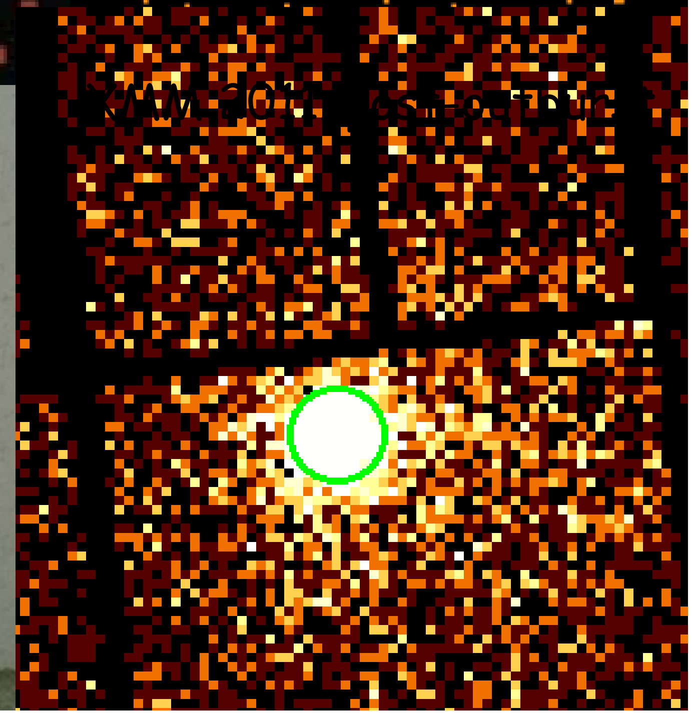
What is the nature of the extended emission?

# XMM and Chandra Observations







Quiescent flux limit (Chandra 2009):

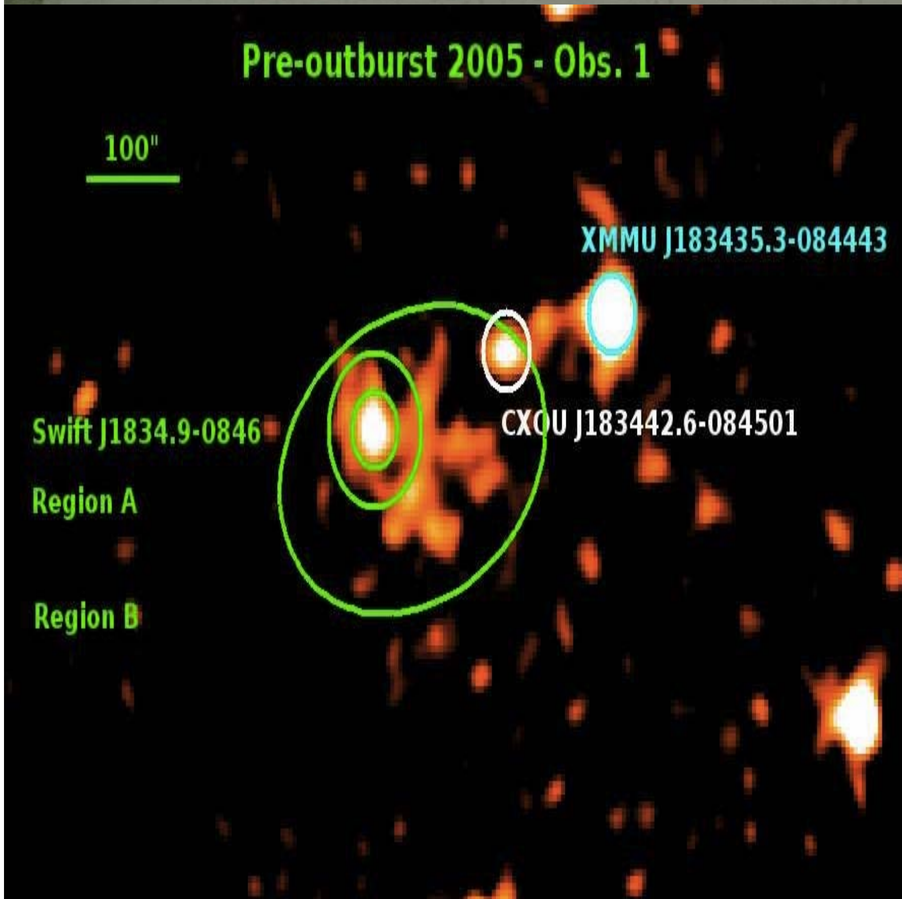
$$F < 4 \times 10^{-15} erg\, s^{-1}\, cm^{-2}$$

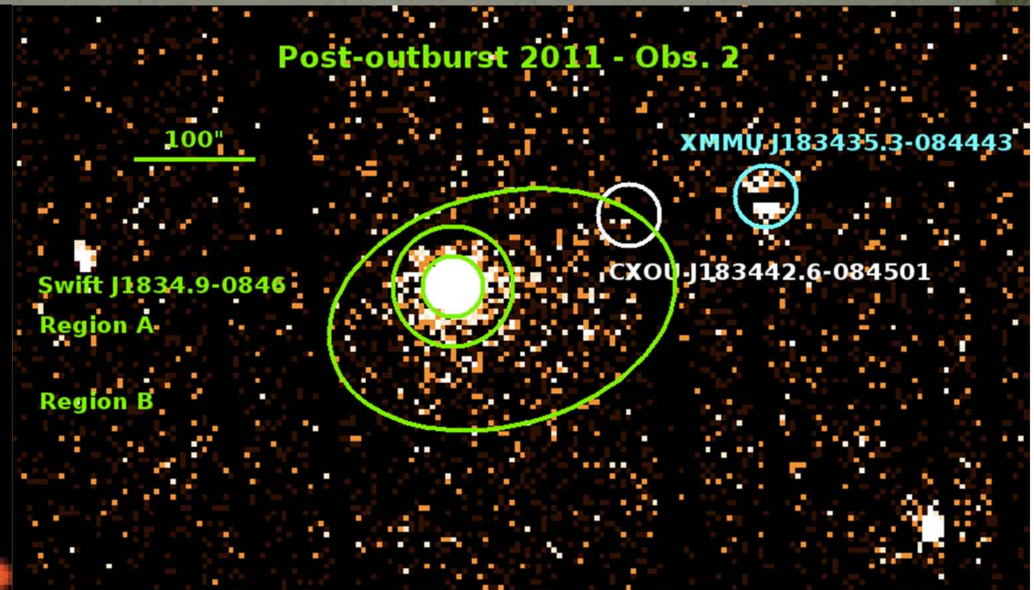
Flux after activity onset (Chandra 2011):

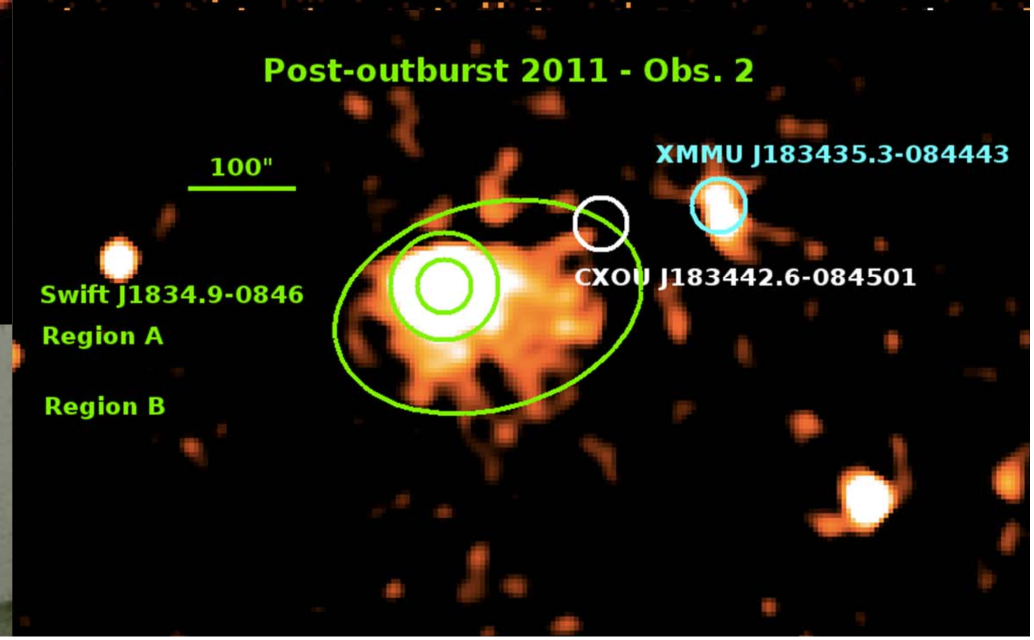
$$F = 1.6 \times 10^{-12} erg\, s^{-1}\, cm^{-2}$$

Younes et al. 2012

# XMM Pre and Post Regions A and B



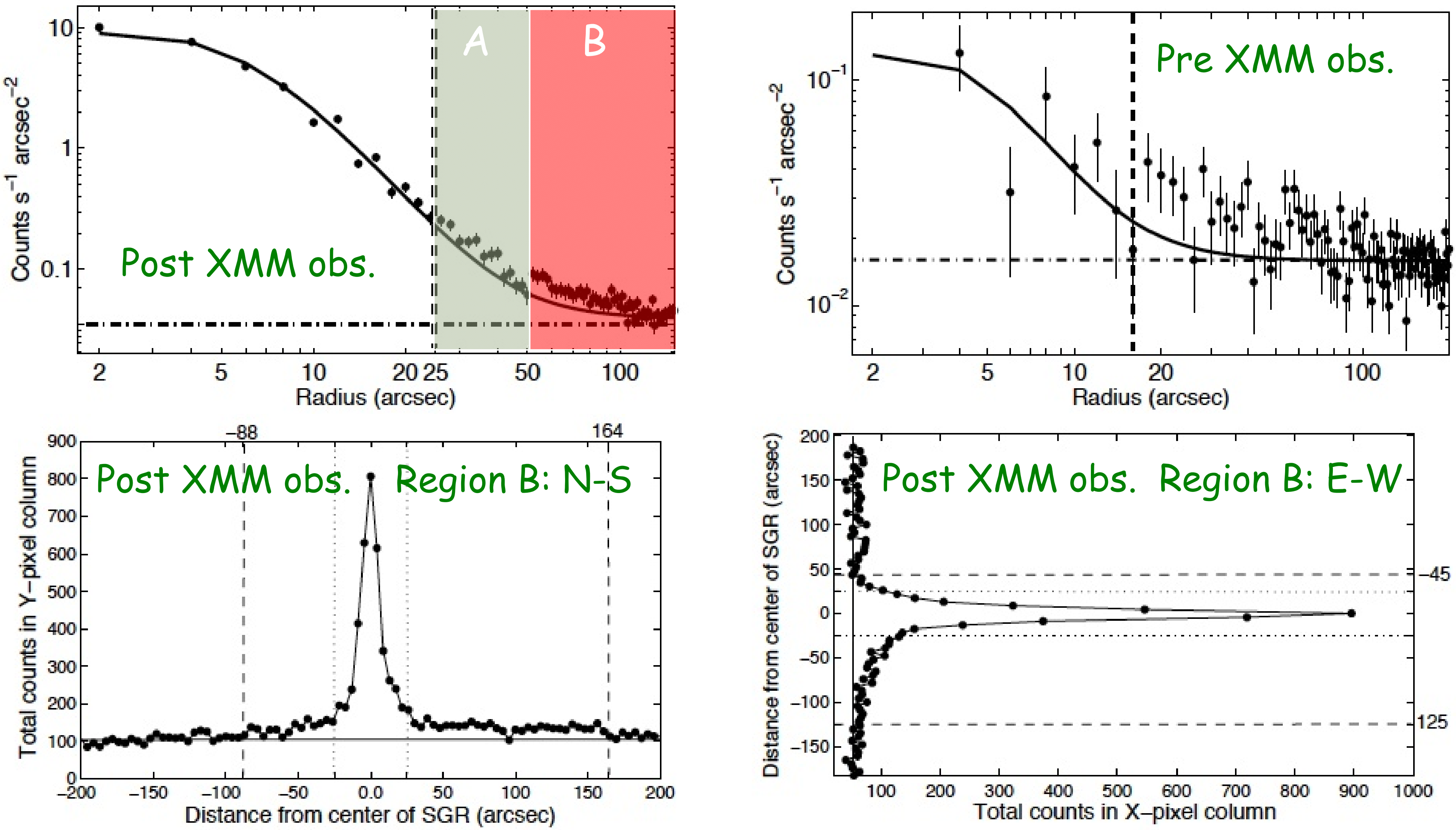




PreSrc $F_{abs}$=4x$10^{-14}$ erg/cm²s (4.6σ)

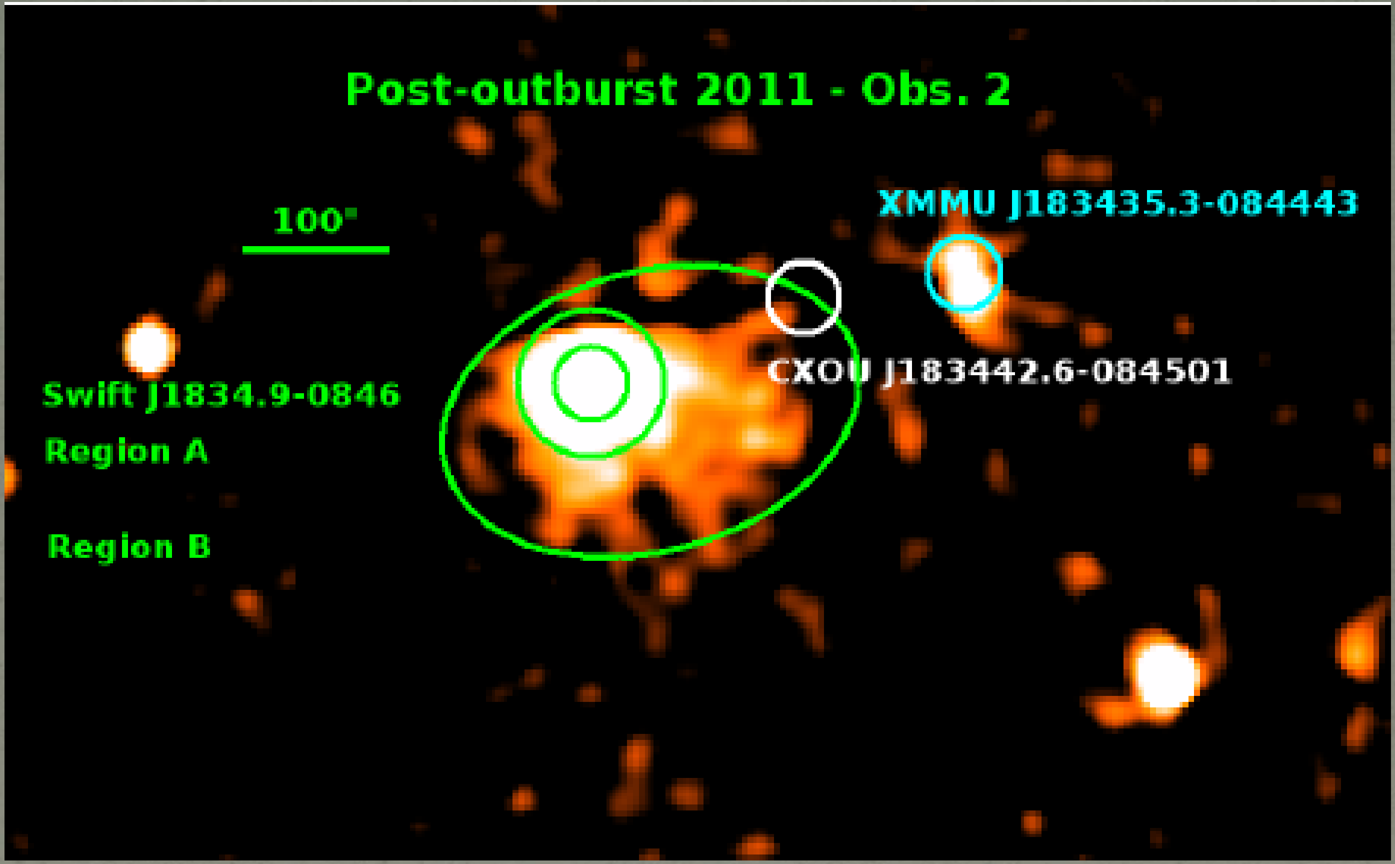
REGION A, circle: 25"<r<50" (1pc)

REGION B, ellipse: 145" (95") major (minor) axis (1-3 pc)

# XMM Pre-, Post- Extended emission



# SPATIALLY RESOLVED SPECTRA




Spectra (0.5 – 10 keV) for Region A and B are fit with an absorbed power-law:

Same $N_H$: $N_H \approx 10^{23}\, cm^{-2}$

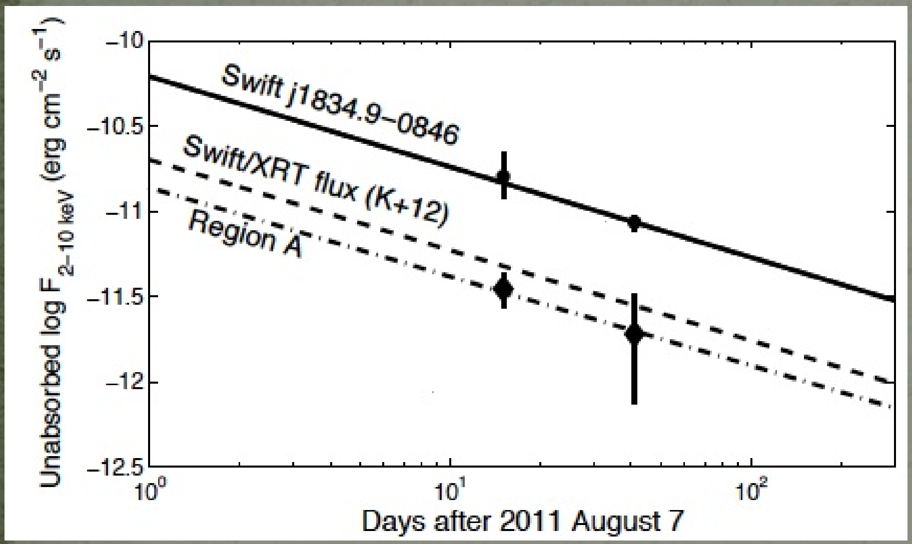
Different Γ: $(\Gamma_{SGR} = 4.1),\ \Gamma_A = 4.6,\ \Gamma_B = 3.2$

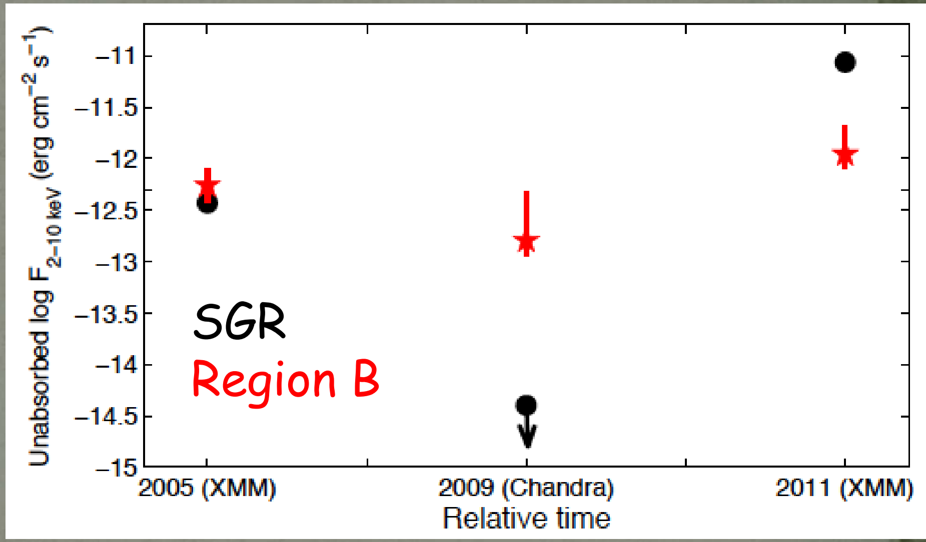
# HALO A and/or B?

**SCATTERING HALO PROPERTIES:**

a. Symmetrical by definition, unless under exotic conditions
b. Needs high density scatterer – indeed Giant Molecular Cloud in the los
c. X-ray spectrum is expected to be softer than the source
d. Halo flux should vary proportionally to source flux (lag depends on distance)

*Region A fits this picture perfectly*
*Region B is inconsistent with these properties*




Region A flux decays following the same power-law as the source: $\alpha\, t^{-0.5}$

Region B was detected pre-outburst, with a slightly weaker flux compared to post-outburst observation

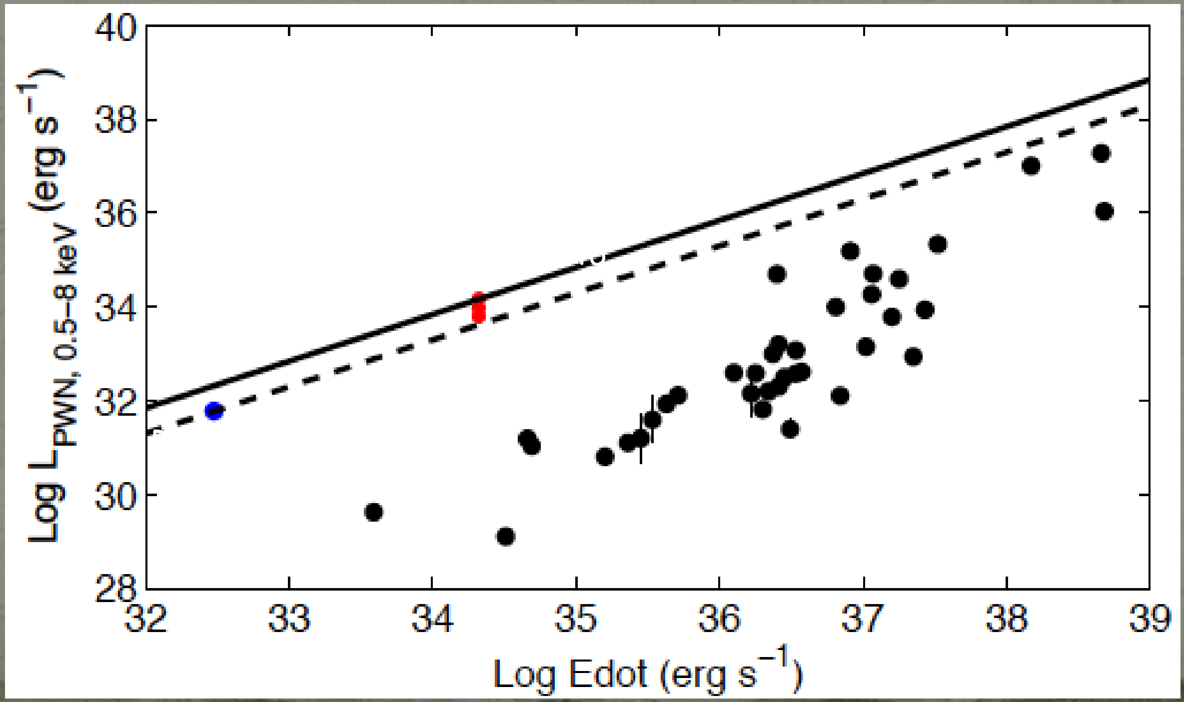
# On the Nature of Region B

PWN are produced by RPPs by rotational energy losses; the efficiency of this process is characterized by: $\eta_X = L_{X,PWN} / \dot{E}_{rot}$ $(10^{-6} < \eta_X < 10^{-2})$

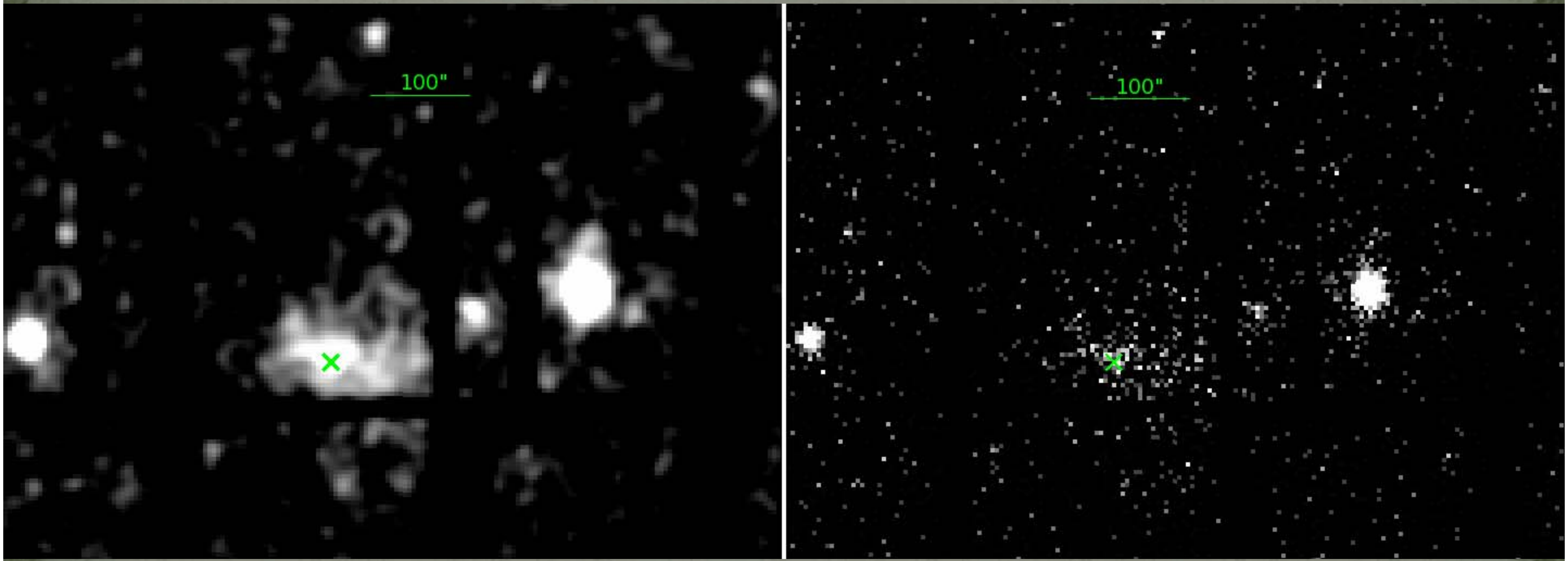
Swift J1834.9-0846 has a very high $\eta_X$ (0.7) similar to RRAT J1819-1458 (0.2)

However if a MWN, it is much softer compared to typical PWN (index 3.2 vs 1-2), suggestive of a very steep electron spectrum (-6). B-field line reconnection?

Assuming that during bursts magnetar $\eta_X$ is similar to RPPs, Region B could be interpreted in terms of a MWN emitting synchrotron emission in a few 10s of μG field at the shock radius of about 25", **when the source is in an active state.**



# Recent XMM observations




XMM 2013 (54ks)

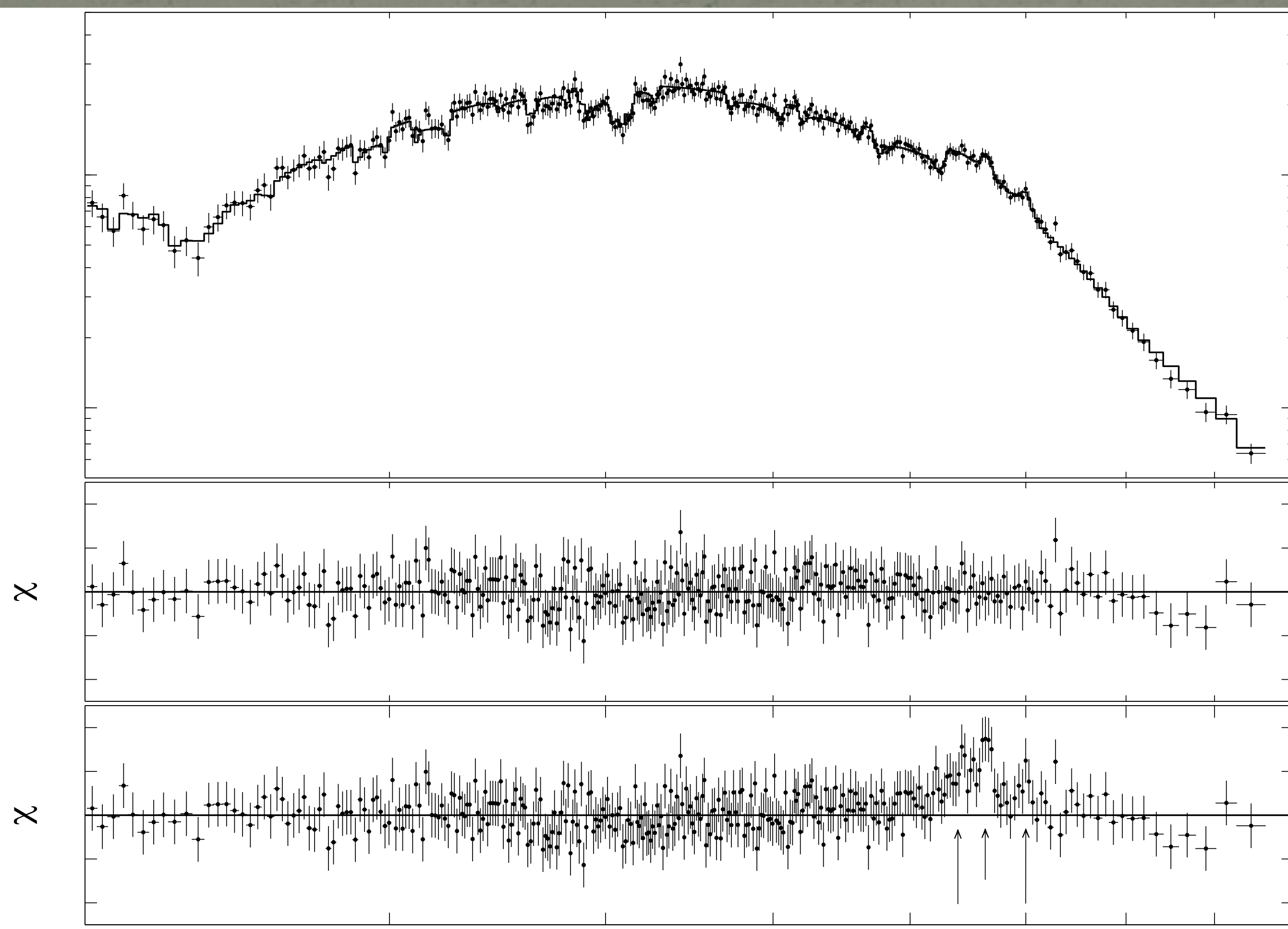
Younes et al, in preparation

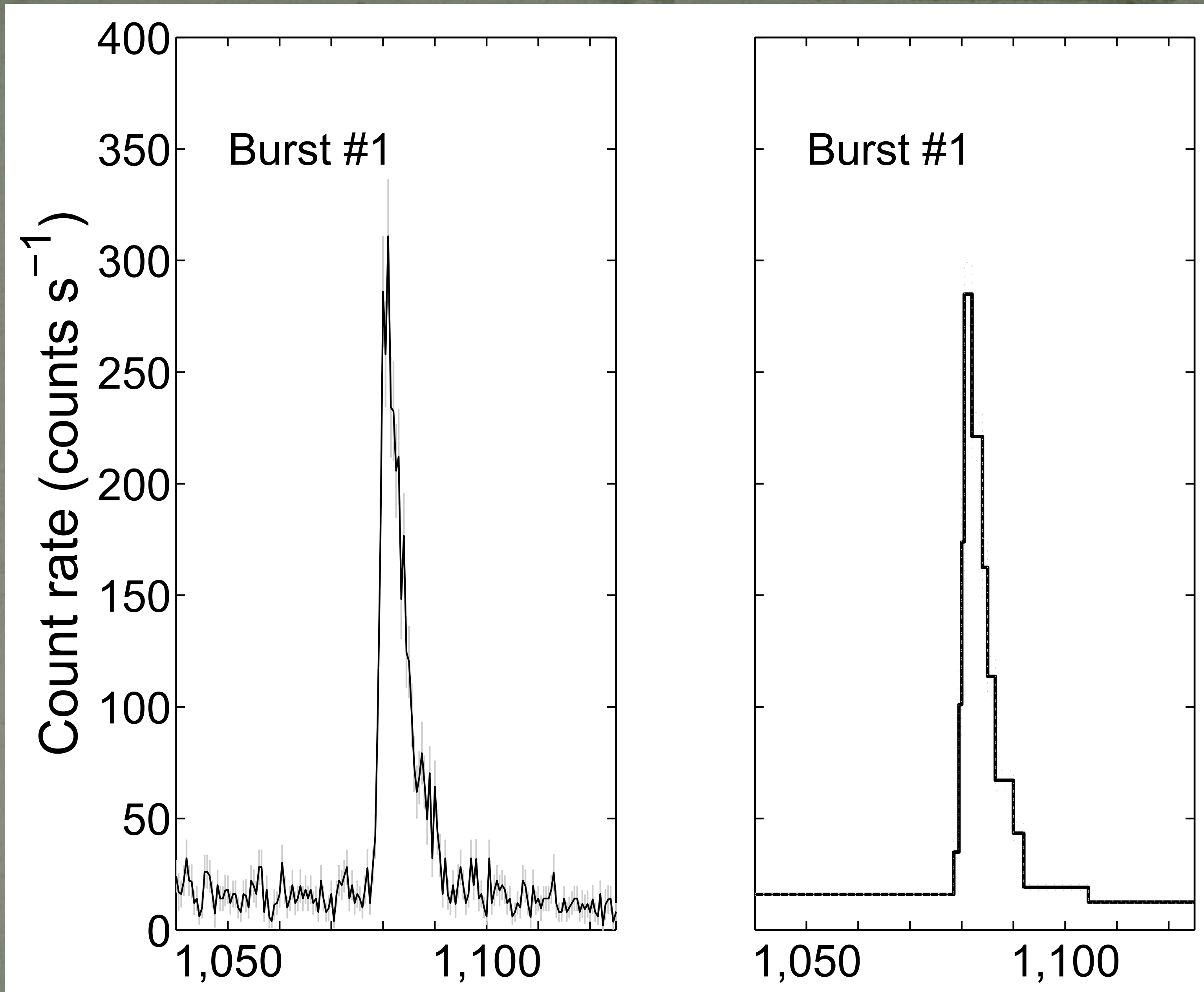
# Conclusions/Questions

- The synchrotron cooling time for B~60 μG is ~ 30 yrs => MWN could be observed in X-rays even when the central source is undetectable!

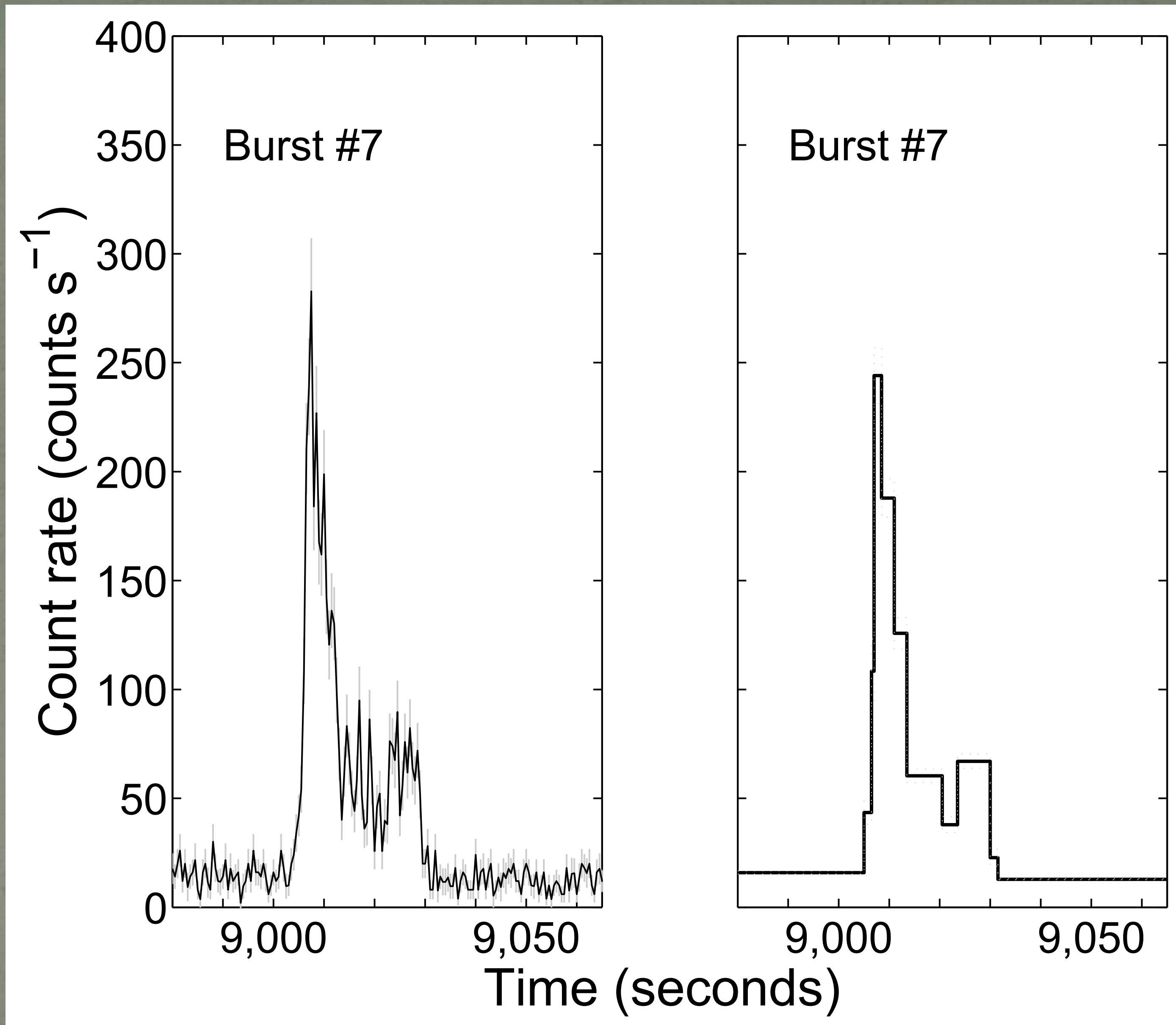
- Are MWNe detectable in other wavelengths? Radio, low-frequencies?

THE BURSTING PULSAR IS BACK AGAIN!

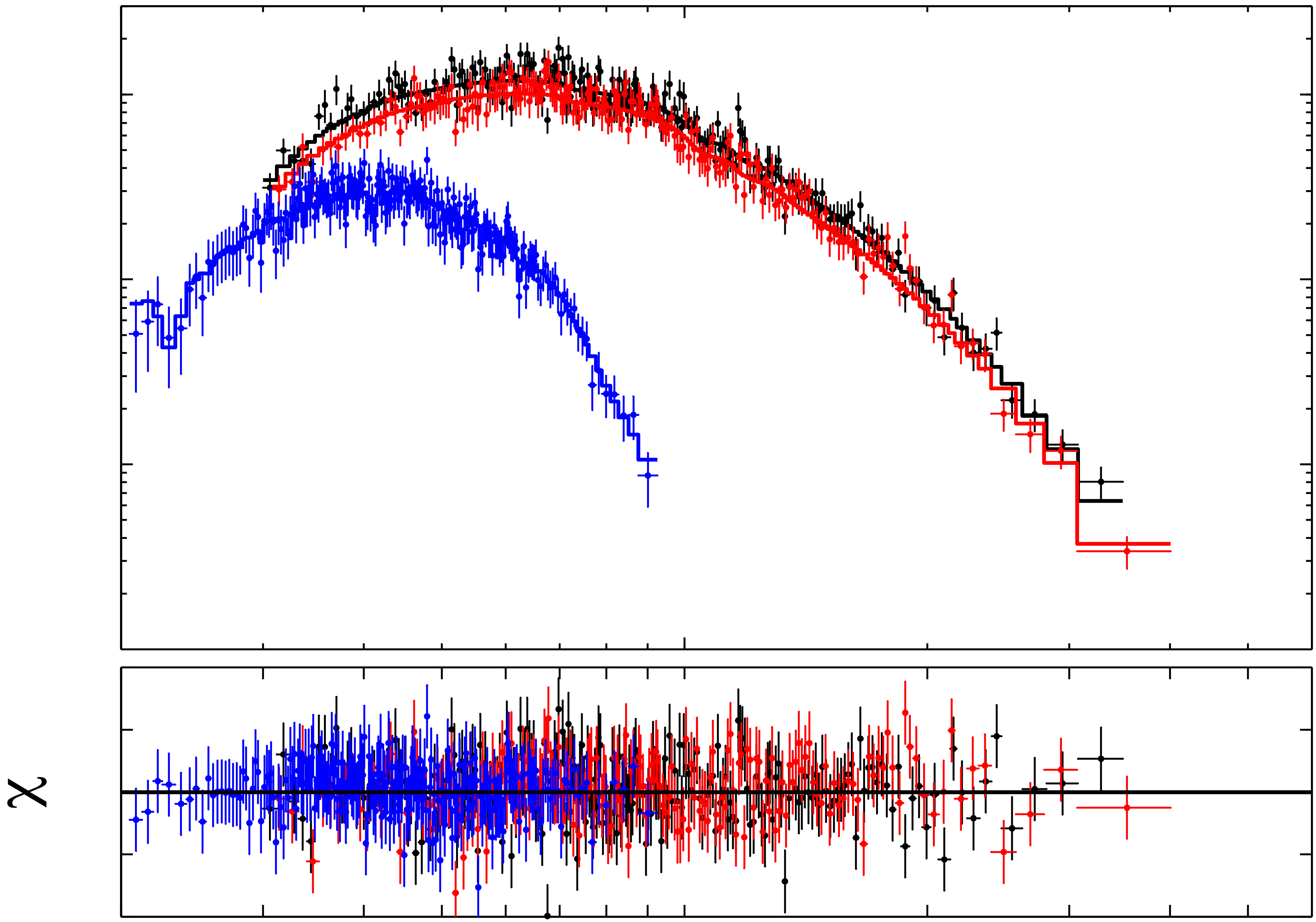

χ
χ

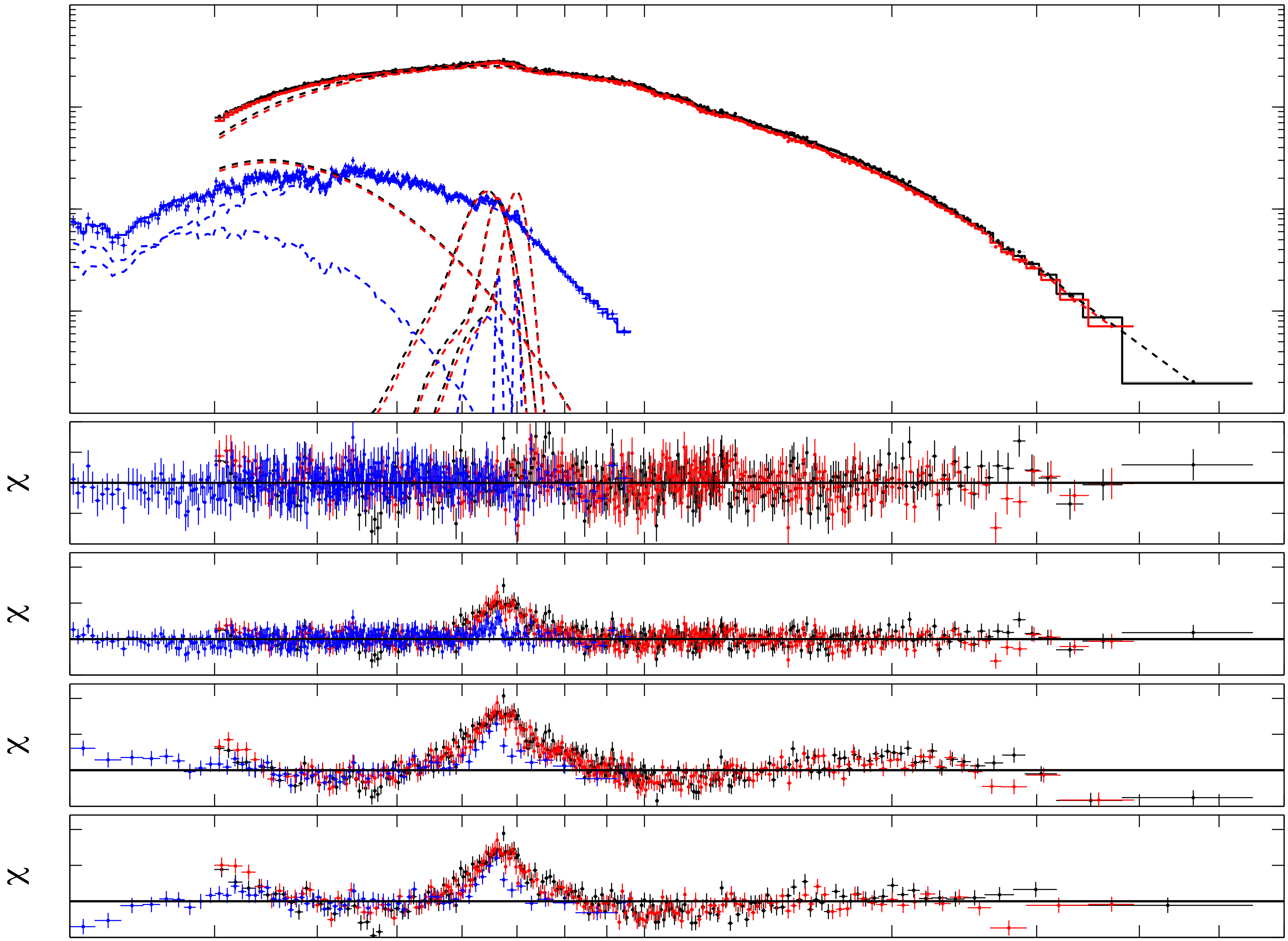


Burst #1
Burst #1
Count rate (counts s$^{-1}$)
0
50
100
150
200
250
300
350
400
1,050
1,100
1,050
1,100

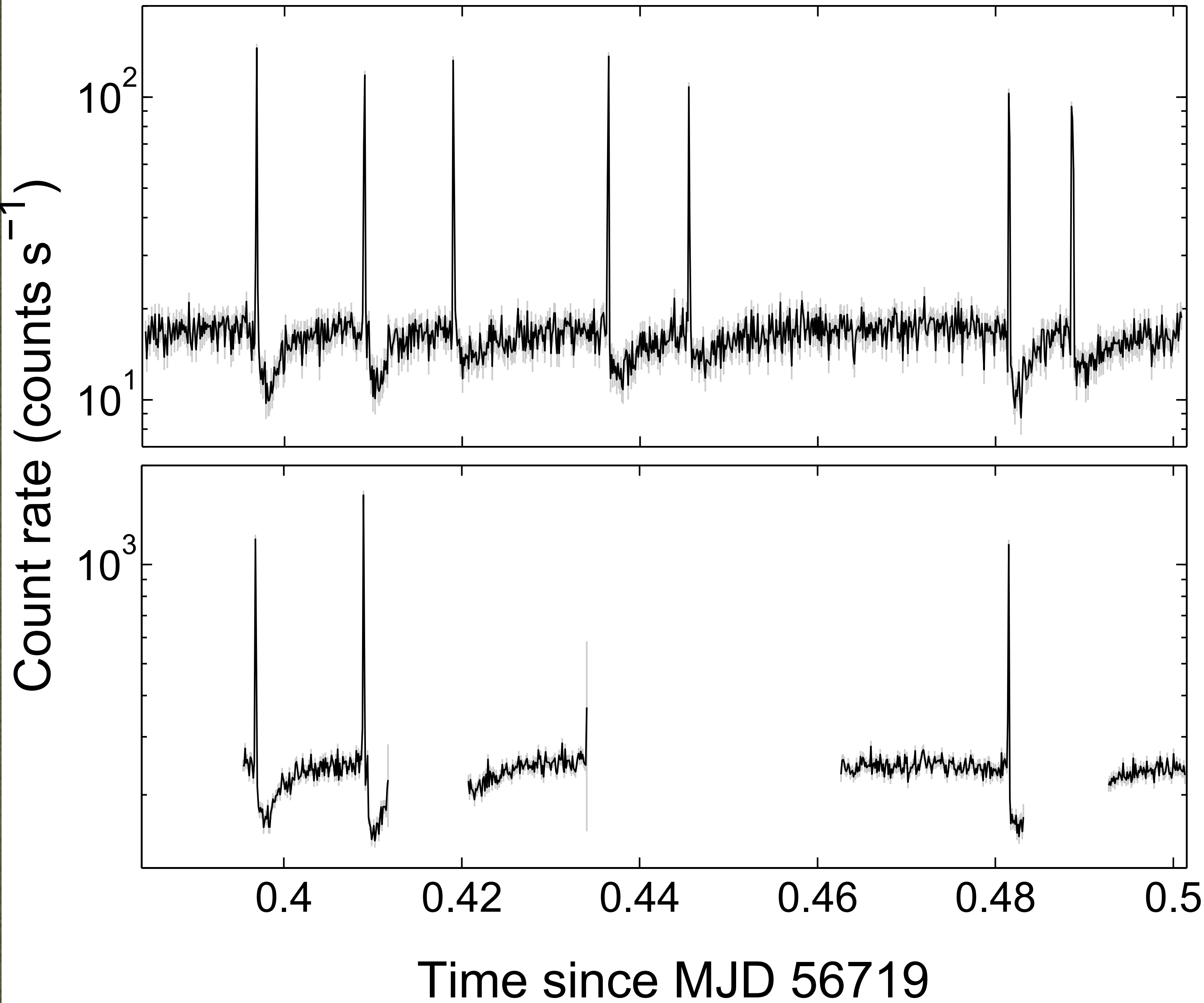


Burst #7
Burst #7
Count rate (counts s$^{-1}$)
400
350
300
250
200
150
100
50
0
9,000
9,050
9,000
9,050
Time (seconds)

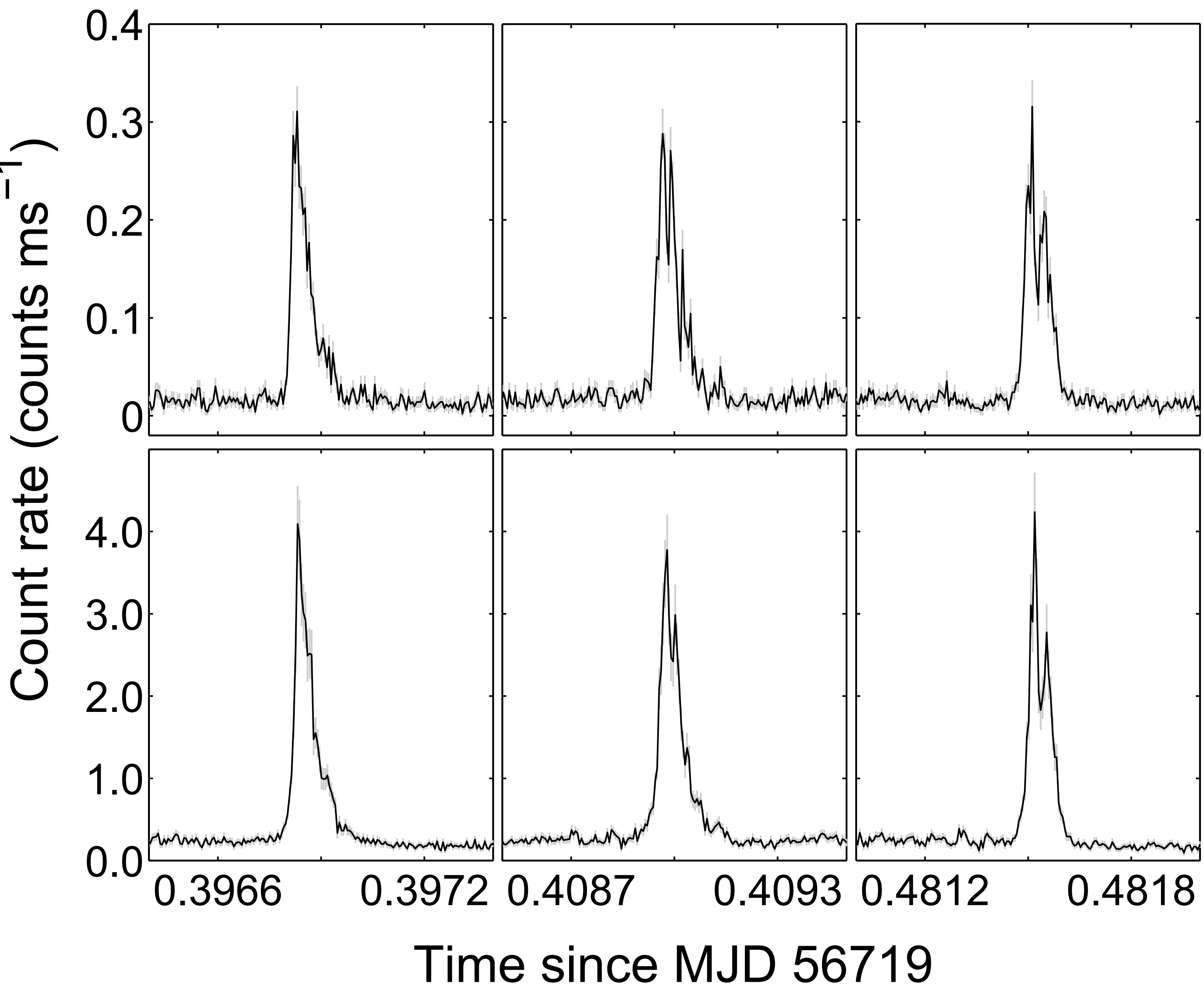

χ



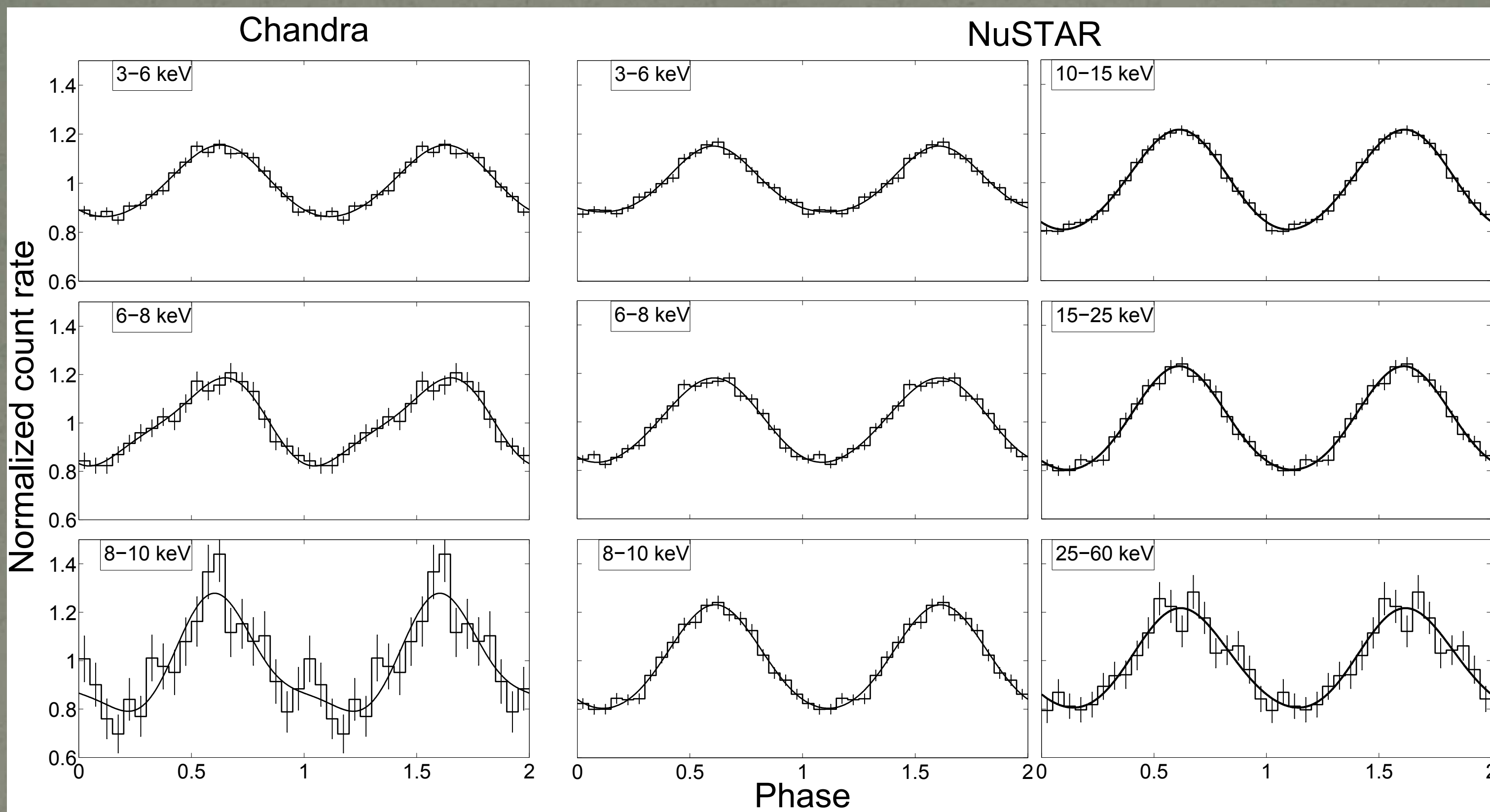
χ
χ
χ
χ

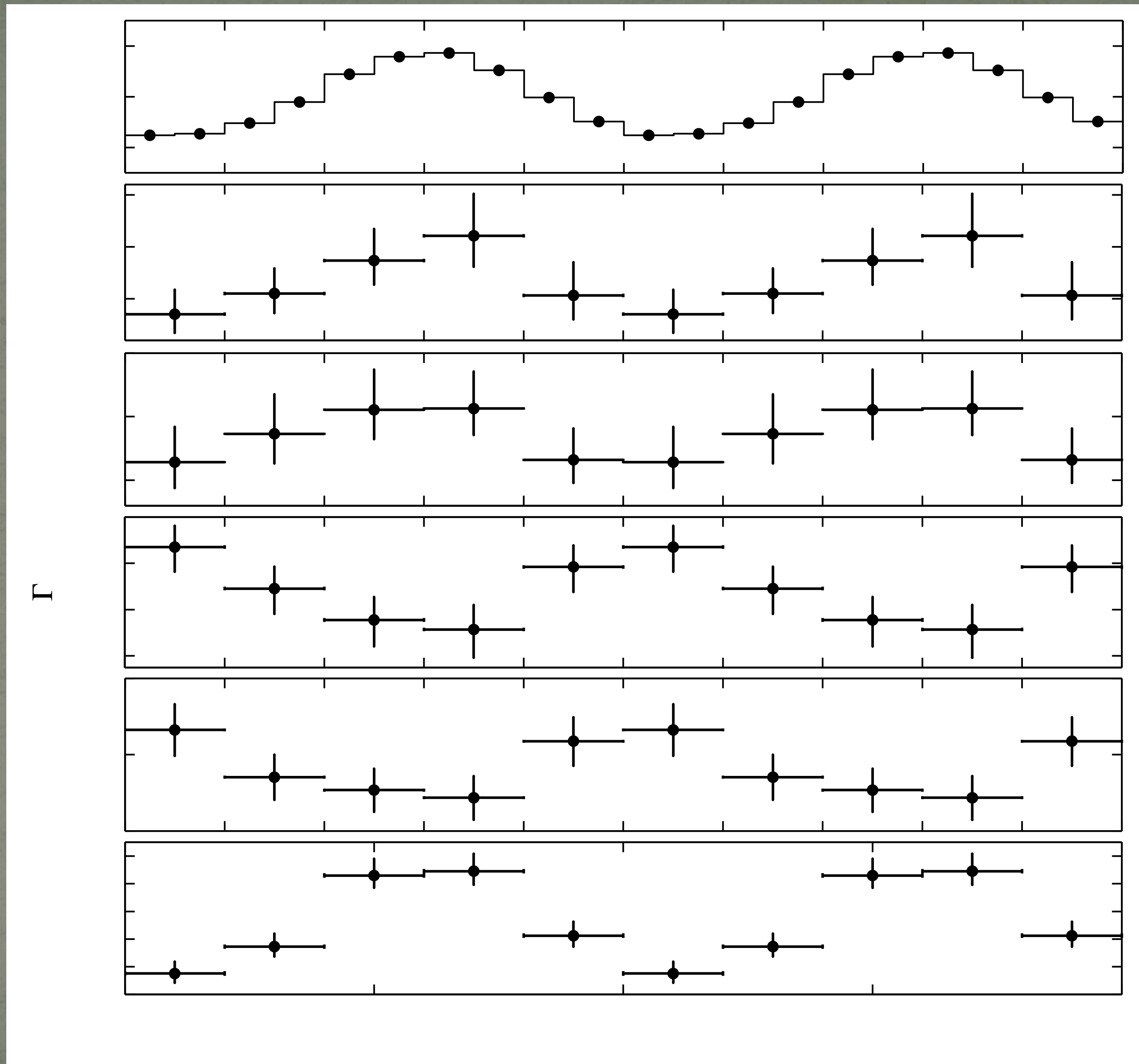


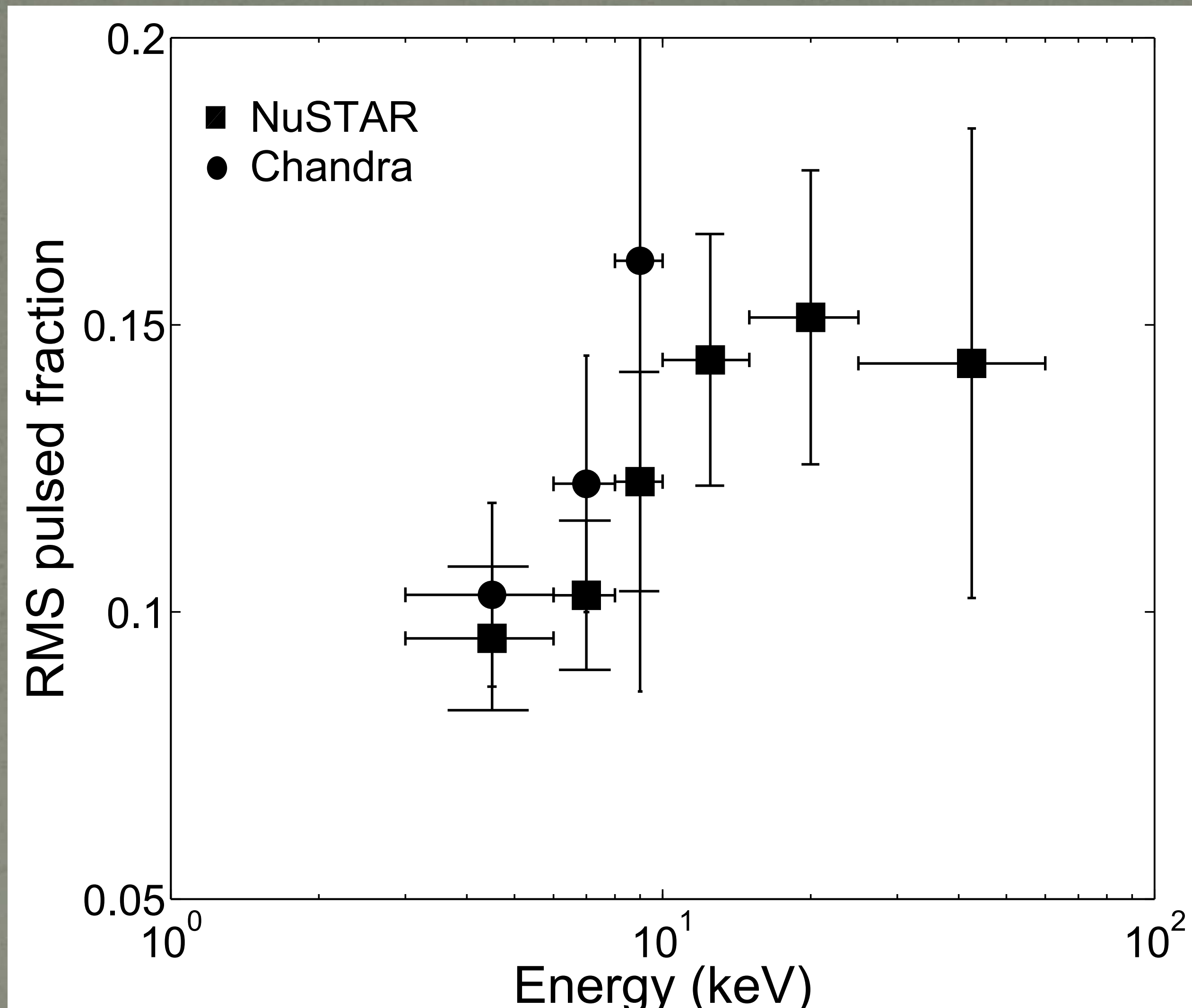
$10^2$
$10^1$
$10^3$
Count rate (counts s$^{-1}$)
0.4
0.42
0.44
0.46
0.48
0.5
Time since MJD 56719



Count rate (counts ms$^{-1}$)
0.4
0.3
0.2
0.1
0
4.0
3.0
2.0
1.0
0.0
0.3966
0.3972
0.4087
0.4093
0.4812
0.4818
Time since MJD 56719


Chandra
NuSTAR
3−6 keV
6−8 keV
8−10 keV
10−15 keV
15−25 keV
25−60 keV
Normalized count rate
Phase
0.6
0.8
1
1.2
1.4
0
0.5
1
1.5
2


Γ



NuSTAR
Chandra
RMS pulsed fraction
Energy (keV)
0.2
0.15
0.1
0.05
$10^0$
$10^1$
$10^2$